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THE LONG-TERM OUTCOME OF KIENBÖCK`S DISEASE

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ACADEMIC DISSERTATION

Esitetään Helsingin yliopiston lääketieteellisen tiedekunnan suostumuksella
julkisesti tarkastettavaksi lokakuun 2. päivänä 2020 klo 12.

Academic dissertation to be publicly discussed, with the permission
of the Medical Faculty of the University of Helsinki, in the auditorium
of the Orton Ortopaedic Hospital, Tenholantie 10, Helsinki,
on Friday 2nd of October 2020, at 12 noon.

Helsinki 2020

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ISBN 978-952-69408-0-9 (nid)
ISBN 978-952-69408-1-6 (PDF)
ISSN 1455-1330

Unigrafia
Helsinki 2020

To Liisa

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LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original publications, which are referred to in the text by their Roman numerals I-IV.

I Viljakka T, Tallroth K, Vastamäki M. Long-term natural outcome (7 to 26 years) of Lichtman stage III Kienböck`s lunatomalacia. Scand J Surg 2016 Jun;105(2):125-132. doi: 10.1177/1457496915577023. Epub 2015 Apr 10.

II Viljakka T, Tallroth K, Vastamäki M. Long-term outcome (22–36 years) of silicone lunate arthroplasty for Kienböck's disease. J Hand Surg Eur 2014;39:405–415. DOI: 10.1177/1753193413489460

III Viljakka T, Tallroth K, Vastamäki M. Long-term outcome (20-33 years) of radial shortening osteotomy for Kienböck`s lunatomalacia. J Hand Surg Eur 2014;39:761–769. DOI: 10.1177/1753193413512222

IV Viljakka T, Tallroth K, Vastamäki M. Long-term clinical outcome after titanium lunate arthroplasty for Kienböck disease. J Hand Surg Am. 2018; (10):945-954. doi.org/10.1016/j.jhsa.2018.02.009

ABSTRACT

Numerous surgical methods have been used in the treatment of Kienböck's disease, methods based on either modification of the lunar load, improvement of the blood flow of the lunate, or are based on removal of the damaged lunate and its replacement by various materials. Recent steps have been total wrist arthrodesis and a proximal row carpectomy. The etiology of the disease is still unclear, with little research available on the natural course. No reliable comparison has been presented of the different treatment methods, and treatment options are based on the results with various therapies at different stages of the disease.

The purpose of our study was to discover the results in long-term follow-up from three different surgical procedures and prognosis for untreated patients. Surgical treatments included silicone implant arthroplasty, SLA (53 patients), radial shortening osteotomy, RSO (16 patients), and titanium implant arthroplasty (11 patients); the untreated group comprised 8 patients. The studies were retrospective and non-randomized. RSO was done for ulna minus variance patients. The degree of disease was in all groups mainly Lichtman-Degnan stages IIIA-IIIB. The follow-up times were 27 years for silicone implants, 25 years for osteotomies, 11 years for titanium implants, and 18 years for untreated patients (27 years from onset of symptoms). In SLA the result was impaired by silicone-induced synovitis and bone cyst formation in 78% of patients. Revisions were made for 22%. In osteotomies, the progression of the disease led to two revisions (12%) and four osteotomies (25%) had poor results. With a titanium implant, poor results were associated with two implant dislocations. Silicone-implant patients and untreated patients had the highest incidence of pain at rest and during exertion (VAS during exertion 5.2 in both). Full pain-relief ranged from 0% (natural) to -21% (osteotomy). Range of motion (ROM) and grip strength improved in all groups but remained generally significantly worse than on the healthy side. In the osteotomy group, ROM (88%) and grip strength (95%) were the best. Radiological changes progressed in each treatment group. In silicone-implant patients, arthrosis existed in 91%, and our arthrosis index was highest, 7.7 / 15. Wrist collapse increased as well. In osteotomies, arthrosis existed in 71% and for titanium-implant patients in 45% with an index of 4.4 in both. With untreated, arthrosis was in 89 % and an index of 5.4. However, untreated disease did not lead to severe arthrotic changes. Functional ability remained good according to the DASH score: in osteotomies 6.1, with titanium implants 9.6, and for those untreated 11.3, while in silicone-implant patients it was 25.4. The corresponding result was in terms of working ability: in silicone-implant patients, 21% were incapacitated and for osteotomies this was 7%. Of the untreated patients, 25%

had switched to lighter work, as had 9% of titanium-implant patients. The results according to Mayo wrist scoring were similar, with the best score for osteotomies, 79, and the worst for silicone-implant patients, 54.8. Osteotomy yielded a clear benefit for 75% of the patients in long-term follow-up, although the failure rate was high, 25%. The functional result of untreated Kienböck`s patients was moderately good, although their wrist degenerative changes increased. The result from titanium implants was skewed by two dislocations, and the operative techniques currently do not completely eliminate this problem. Moreover, treatment indications require further attention. In future, prospective studies would be needed to better assess the role and importance of surgical treatments. Similarly, the natural course of the disease should also become better known, so that the actual effect of these treatment methods on the course of the disease would become clear.

TIIVISTELMÄ

T. Viljakka

Kienböckin taudin hoidosta pitkäaikaistuloksia on julkaistu vähän, eikä taudin luonnollisesta kulusta ole riittävästi tietoa. Selvitimme käyttämiemme kolmen leikkaushoidon pitkäaikaistuloksia Sairaala Ortonin ja Tampereen yliopistollisen sairaalan potilaistoista sekä tiedostoista löytyneiden hoitamattomien potilaiden pitkäaikaistulosta. Hoitoryhminä oli silikoni-implanttiartroplastia, (SLA) radiuksen lyhennysosteotomia, (RSO), titaani-implanttiartroplastia, (TLA) ja neljäntenä hoitamattomat, ”natural course”. SLA-potilaita oli 53 (54 rannetta), RSO-potilaita 14, TLA-potilaita 11 ja hoitamattomia 8 (9 rannetta).

Aineistot olivat retrospektiivisiä ja pieniä taudin harvinaisuudesta johtuen. Alkututkimuksissa kivun arvioinnissa VAS-indeksiä ei ollut käytössä eikä myöskään DASH-pisteytystä toiminnallisen tilan arvioimiseksi. Hoitotiedot saatiin sairauskertomuksista ja röntgenkuvat olivat käytettävissä lähes kaikista potilaista. Kliinisen tutkimuksen lisäksi kipu rekisteröitiin VAS-asteikolla ja toiminnallinen tulos DASH-ja MWS-pisteytyksellä. Molemmat ranteet röntgenkuvattiin. Tuloksia verrattiin tilastollisesti hoitoa edeltäviin sekä terveen puolen arvoihin. Seuranta-ajat olivat keskimäärin SLA:ssa 27 (32-36) vuotta, RSO:ssa 25 (20-33) vuotta, TLA:ssa 11 (5.4-15.3) ja hoitamattomilla 18 (7-26) vuotta.

Potilaiden keski-ikä hoidon alussa eri ryhmissä vaihteli 32 vuodesta 34 vuoteen, TLA-aineistossa 47 vuotta ja miesten osuus oli 72-100 %. Raskaan työn tekijöitä aineistoissa oli TLA:aa lukuun ottamatta enemmistö. Oikea ja dominantti ranne sairastui yleisimmin. Oireiden keston mediaani oli SLA:ssa 19.5, RSO:ssa 23, TLA:ssa 19 ja hoitamattomilla 48 kuukautta.

Lunatummalasian Lichtman-Degnan luokka oli valtaosin IIIA-IIIB. SLA:ssa oli lisäksi kolme luokkaa IV, ja RSO:ssa yksi luokka II. Luokka IIIB:tä oli SLA:ssa 31 %, RSO:ssa 7 %, TLA:ssa 45 % ja hoitamattomilla 22 %. Karpuksen korkeus (CHR) vaihteli 0.49 -0.51 ja Ståhl-indeksi välillä 39-45 (normaaliarvot 0.54 ja 50). OA-indeksi vaihteli välillä 3 -3.3, joten artroosimuutokset olivat hyvin vähäisiä (3/15 indeksi normaali). Radiologisin kriteerein lähtötilanne RSO-ryhmässä oli paras ja TLA-ryhmässä huonoin, joskin erot olivat vähäisiä.

Täysin kivuttomia oli SLA:ssa 11 %, RSO:ssa 21 %, ja TLA:ssa 18 %. Hoitamattomista potilaista kukaan ei ollut täysin kivuton. Kipu VAS-asteikolla (0-10) levossa oli keskimäärin SLA:ssa 2.2, RSO:ssa 0.9, TLA:ssa 0.5 ja hoitamattomilla 3.1. Voimakkaassa rasituksessa VAS oli SLA:ssa 5.2, RSO:ssa 3.0, TLA:ssa 2.7 ja hoitamattomilla 5.2. Keskimääräinen DASH oli SLA:ssa 25.4, RSO:ssa 6.1, TLA:ssa 9.6 ja hoitamattomilla 11.3. Työkyvyttömiksi jäi SLA:ssa 21 % ja RSO:ssa 7 % ja kevyempään työhön siirtyi vastaavasti SLA:ssa 11 %, RSO:ssa 14 %, TLA:ssa 9 %

ja hoitamattomista 25 %. Revisioleikkauksia oli SLA:ssa 22 % ja RSO:ssa 12.5 %. SLA:ssa ongelmat liittyivät pääosin silikonin aiheuttamaan synoviittiin, joka johti 9 tapauksessa revisioon. Ranneluiden kystamuutoksia oli 78 %:lla potilaista. RSO:ssa taudin progressio johti revisioleikkaukseen (arthroplastia ja arthrodeesi) kahdella potilaalla, jotka poistettiin loppuarviosta. Lisäksi kahdelle tehtiin radiuksen luudutusleikkaus ja kahdelle ulnan pään pinteen korjaus. Näistä kahdella tulos oli huono. TLA:ssa oli kaksi implantin dislokaatiota (18 %), joista toinen on operoitu noin vuosi follow-up tutkimuksen jälkeen. Mayo wrist score (MWS) oli SLA-aineistossa keskimäärin 54.8, RSO:ssa 79, TLA:ssa 68 ja hoitamattomien aineistossa 70. Mayo wrist scoringilla SLA:ssa erinomaisia tai hyviä oli 5 % ja huonoja 63 %, RSO:ssa 43 % ja 7 %, TLA:ssa 18 % ja 27 % ja hoitamattomissa 25 % ja 12 %. Ekstensio-fleksioliike ja deviaatiot paranivat muissa ryhmissä paitsi SLA:ssa, jossa vain ulnaarideviaatio ja ekstensio paranivat lievästi. Puristusvoima parani vastaavasti ollen SLA:ssa 72 %, RSO:ssa 95 % LTA:ssa 81 % ja hoitamattomilla 93 % terveen puolen keskimääräisestä arvosta. SLA:ssa ranteen kollapsi lisääntyi ja artroosimuutokset progredioivat. Artroosia oli 91%:lla (indeksi 7.7/15). RSO:ssa indeksit säilyivät paitsi Ståhl-indeksi. Artroosia oli 71%:lla indeksin ollessa 4.4. TLA:ssa artroosi-indeksi oli niin ikään matala, 4.4 ja artroosia oli 45%:lla. Hoitamattomilla karpuksen korkeusindeksi huononi, ja Ståhl indeksi laski. Artroosi-indeksi oli 5.4, ja artroosia oli 89 %:lla. Lichtmanin luokituksella lunatumin luokitus huononi RSO:ssa 36 %:ssa ja hoitamattomilla 45 %:ssa ranteista.

Tulokset eivät suoraan ole keskenään vertailtavissa tutkimusten ollessa retrospektiivisia. SLA:n tulos oli sekä kliinisesti että radiologisesti huono silikonisynoviitin takia. Noin 10%:lla ei ollut luukystoja ja näillä tulos oli selvästi parempi. SLA:ta ei suositella käytettäväksi Kienböckin taudissa. RSO:n tulos oli kivun ja toimintakyvyn suhteen hyvä 75%:lla vastaten kirjallisuudessa esitettyjä tuloksia. RSO on tutkimuksen perusteella hyvä hoito stage IIIA:ssa ranteissa, joissa on ulnan minusvarianssi. TLA:n tulosta huononsi implantin instabiliteetti, joka vaatii lisäratkaisuja. Hoitamattomien aineistossa kipua oli enemmän kuin RSO:ssa ja TLA:ssa, DASH oli hyvää tasoa, samoin työkyky. Artroosi lisääntyi kaikissa hoitoryhmissä. Taudin luonnollinen kulku vaatii lisäselvitystä yhtenäisin kriteerein, ja eri hoitojen tulosta olisi selvitettävä prospektiivisin seurannoin.

LIST OF ABBREVIATIONS

CHR	carpal height ratio
CO	capitate osteotomy
CRPS	Complex Regional Pain Syndrome
CSO	capitate shortening osteotomy
CT	computed tomography
CUDR	carpal ulnar distance ratio
DASH	Disabilities of the Arm, Shoulder and Hand
ECA	extensor compartment artery
ECU	extensor carpi ulnaris
EPL	extensor pollicis longus
FCR	flexor carpi radialis
MRI	magnetic resonance imaging
MWS	Mayo wrist score
PRC	proximal row carpectomy
PRWE	Patient-Rated Wrist Evaluation
RCWO	radial closing wedge osteotomy
RLA	radiolunate angle
ROM	range of motion
RSA	radioscaphoid angle
RSO	radial shortening osteotomy
SLA	silicone lunate arthroplasty or scapholunate angle
SLAC	scapholunate advanced collapse
STT	scaphotrapeziotrapezoidal
TFCC	triangular fibrocartilage complex
TLA	titanium lunate arthroplasty
ULO	ulnar lengthening osteotomy
VAS	visual analogic scale

FIGURES

TABLES

1. INTRODUCTION

A healthy wrist is necessary for the normal use of the hand. One cause of wrist disorders is Kienböck`s disease or lunatomalacia or avascular necrosis of the lunate bone. Kienböck`s disease causes pain both at rest and especially during activity. It significantly reduces the range of motion of the wrist in every direction, thus disabling the use of the hand. It often causes inability to work and features longstanding pain and deteriorated function.

This thesis deals with the long-term outcome of Kienböck`s disease. The theme for this retrospective study arose from the possibility to explore a large cohort of Kienböck`s disease patients diagnosed and treated in the same hospital by a few experienced hand surgeons with a similar protocol, giving the possibility to evaluate its long-term outcome and prognosis, especially because the hospital had saved all roentgenograms since 1940 for clinical and scientific use. Although hundreds of articles already exist on Kienböck`s disease, the outcome still remains controversial (Innes and Strauch 2010). Only a few studies concentrate on the natural course (Kristensen et al. 1986, Fujisawa et al. 1996), long-term outcome after silicone implant arthroplasty (Kaarela et al. 1998), long-term outcome after titanium implant arthroplasty (Swanson et al.1997) or long-term outcome after radial shortening osteotomy (Koh et al. 2003, Zenzai et al. 2005, Raven et al. 2007, Watanabe et al. 2008, Rodrigues-Pinto 2012, Matsui et al. 2014, Luegmair et al. 2017). These were the main themes for this thesis.

An Austrian radiologist Robert Kienböck (1871-1953), a pioneer in the use of X-ray technology for medical diagnosis and therapy, described a disorder in which the lunate bone in the wrist would break down. Kienböck called the disorder "lunatomalacia". He published his findings in a study titled *Über traumatische Malazie des Mondbeins und ihre Folgezustände*: Entartungsformen und Kompressionsfrakturen (1910). The disorder was later called "Kienböck's disease". Now, one hundred years later, we sought the end results and the long-term outcome of our unique population of Kienböck`s disease patients.

2. REVIEW OF THE LITERATURE ON KIENBÖCK`S DISEASE

2.1. HISTORY

The diagnosis of lunatomalacia, as well as of many other diseases, was made possible after development of the X-ray examination for clinical use. Wilhelm Conrad Röntgen published on his invention in 1895, and in 1910, an Austrian radiologist named Robert Kienböck published an article entitled "Über traumatische Malazie des Mondbeins und Ihre Folgzustände: Entartungsformen und Kompressionfrakturen" (1910). Kienböck, one of the pioneers in radiology, developed extensive diagnostics of bone diseases and tumors, also developing experimental and clinical use of radiotherapy. In his 1910 article, Kienböck described 16 patient cases that showed typical X-rays in various stages of the disease. He presented the disease as having as its possible etiology, the lunate's nutritional disorder due to the damage of ligaments and vascular damage following the lunate's contusion, strain, or subluxation. Trauma etiology was therefore likely.

At that time, only 16 articles had appeared in the whole literature concerning the wrist area, its anatomy, injury, or surgery; wrist injuries were generally considered anomalies. Peste had described a lunate fracture in a cadaver in 1843 (Peste JL: Discussion. Bull Soc Anat 18: 169, 1843). The patient died as a result of multiple injuries received after a fall. In the United States, the first cases of lunatomalacia were published by Müller in 1920.

In 1928, Hultén published his study on ulnar variance, which was radiologically neutral in 61% of 400 normal subjects, in 23% negative, and in 16% positive (the ulna being "longer" than the radius). In 23 lunatomalacia patients, he found ulnar variance to be negative in 17 (74%) and neutral in 6 (26%). Hultén considered a lunate fracture as a primary cause of the disease. He also performed RSO for one patient (Hultén 1935).

Variance theory was level of turning point in the history of lunatomalacia. Subsequently, a number of studies were conducted based on the theory of ulnar variance, the first of which was published by Persson in 1945 (3 RSOs and 16 ULOs) (Persson 1945). Persson published in 1950 good results on ULO in 14 patients (Persson 1950). Subsequently, results after surgical treatment based on variance theory have been widely published.

In 1970, Alfred B. Swanson launched a lunate silicone implant, replacing the damaged lunate (Swanson 1970). In the 1970's and 1980's, patients treated with that method were introduced in several studies and at short-term follow-ups,

in which the results were promising until complications caused by the implant material changed the situation (Eiken et al. 1985, Carter et al. 1986, Alexander et al. 1990). Additionally, replacement of the lunate with biomaterials had been introduced. Nahigian published in 1970 on his method using the dorsal fascial structure of the wrist (Nahigian et al. 1970). Tendon tissue has also served as a substitute for the lunate.

The stage of lunatomalacia is estimated by convenional X-ray images. The aim of the classification has been to evaluate disease prognosis and to standardize treatment. Ståhl published his classification in 1947 (Ståhl 1947), based on which Lichtman and Degnan developed the currently existing classification (Lichtman and Degnan 1993). Moreover, MRI is currently included in the classification (Lichtman et al. 2010), and an arthroscopic classification of the disease also exists (Bain and Begg 2006). Classifications aim at systematizing treatment and improving assessment of treatment outcomes

There exists no single concept of disease management even today. Treatment procedures and theories vary, but lunate preservative treatments have adopted more and more fields: mechanical lunate decompression measures versus conservative non-surgical treatment, and lunate vascularization-enhancing measures. The second line is reconstructions of the lunate with bone grafts and the more radical measures including lunate removal. The basic problem is that the etiology of the disease is still under debate.

2.2. EPIDEMIOLOGY

Due to the rarity of the disease, epidemiology has attracted little research. Mennen and Sithebe (2009) published on 1287 patient records on which wrists were imaged. They found asymptomatic lunatomalacia (Stages II-IV) in 23 patients (1.9%). Of these, 63% were men of a mean age of 49, and women, 46.5 years. They all had unilateral disease in the dominant hand. Ulnar variance was neutral in 57% and negative in 43%. The imaging technique was both wrists imaged on the same film at the same time. This study was conducted in Pretoria, South Africa.

Van Leeuwen et al. (2016) examined retrospectively the radiological data of more than 51,000 patients. Of these, 87 patients, 0.17%, had lunatomalacia, and in 51 cases (0.10%), the disease was found incidentally. Advanced Stage III to IV was evident in 18% of the incidental findings and in 51% of the clinically diagnosed cases. An undiagnosed low-symptomatic disease also occurs, on which, Taniguchi et al., for instance, published data on 14 patients (2002).

Tsujimoto et al. (2015) surveyed 40-year-old and older women in a Japanese community: they numbered 572. Kienböck's disease was found in seven, with

a prevalence of 1.2% for women of this age. Negative ulnar variance was not a contributing factor.

Golay et al. (2016) published on a series with more than 76,000 patient imaging descriptions from over 150,000 either plain roentgenograms or CT scans. Kienböck's disease was detectable in 18 patients, and 5 of these were incidental findings. The prevalence of radiological incidental findings was thus only 0.0066% or 7/100 000. The authors found no explanatory factors between the two groups.

2.3. ANATOMY

2.3.1. Lunate's location and function

The lunate is the central, adaptive part of the proximal wrist bones. The lunate is jointed to the scaphoid and triquetrum with joint surfaces that allow a small sliding / rotation movement in the extremities of the wrist, especially in the radial and ulnar deviations. The bones combine inter-osseal and extra-osseal ligaments whose integrity is important in maintaining normal motion properties. Proximally, the lunate joins the lunate fossa of the radius with congruent joint surfaces, while the twisting radius is the same, whereas distally the capitate joint differs from the previous one in that the head of the capitate is lower in the radius, thereby causing in forced extension increased compression the dorsal part of the lunate (nutcracker effect). Intra-osseal pressure in the lunate can rise to 79 mm mercury (Schiltenwolf et al. 1996). The load on the wrist is caused by the functioning of muscle tension units (extensors, flexors). In this case, when the wrist bones are adapted, the ligaments that support them will lock and support the wrist so that a painless, sturdy grip is possible. When any component is damaged, the function of the wrist is disturbed.

The lunate form may be varied: it may be partially or completely fused to the triquetrum, and a bipartite form also has been described. Bone coalitions have also been described for other wrist bones, e.g. a capitatohamate coalition. Antuna-Zapico (1966) described in his thesis three types of lunate, the first, type I, being trapezoidal in shape, in which the bone trabeculae pass at an angle of about 135 ° to the lunocarpal joint surface. In the II-III types, the shape is rectangular or square, in which the trabeculae of the bone are oriented perpendicularly or almost perpendicularly to radiocarpal joint level. Bone mechanical strength may also be improved in this case. Type I of the lunate is associated with ulna minus variance, to be discussed later. The shape of the lunate is also classified on the basis of whether its medial facet joins to the hamate, type I or not, Type II (Viegas et al.1990). Kienböck's disease was more advanced in type I (Rhee et al. 2015). In

type I, scaphoid translation is greater as well as the extension flexion movement of the radiocarpal joint (Bain et al. 2015).

2.3.2. Lunate blood supply

Arterial blood supply to the lunate comes from the dorsal radiocarpal arch branches, the dorsal intercarpal arch, and sometimes the branches of the anterior interosseus artery. On the palmar side, the blood supply comes from the palmar intercarpal arch, the anterior inter-osseal communicans arteries, and the ulnar recurrent artery. The nutritional artery is located in 20% of the cases volar and in 80% dorsally and volar. The dorsal branches are smaller. Inside the bone, the vascular pattern is Y-shaped (59%, dorsal or palmar), I-shaped (31%, one dorsal and palmar branch communicating) or X-shaped (10%, where two dorsal and two palmar branches communicate with each other). There is only one palmar vessel in 20%. Vascularization is the worst in the proximal part of the lunate (Botte et al. 2004). In the distal and central parts of the bone, vascular anastomosis is more abundant.

Venous blood circulation occurs through dense venous plexuses that are located at the dorsal and palmar surface of the lunate (Pichler and Putz 2002).

Innervation of the wrist is transmitted through nine intra-articular branches: the posterior interosseus nerve, the superficial branch of the radial nerve, the anterior interosseus nerve, the lateral dorsal or posterior and the medial cutaneous nerves of the forearm, the palmar cutaneous branch of the median nerve, the ulnar nerve's lateral branch, the branches in the first metacarpal space, the superficial radial nerve, and the dorsal branch and perforating branches of the ulnar nerve (Cooney 1998).

2.3.3. Etiology of Kienböck`s disease

The etiology of lunatomalacia is still unknown, although the disease itself has been known for over 100 years. The same situation still exists for other osteonecroses, although many of the predisposing or risk factors are known. The situation is described by the term "lunate at risk," suggesting a number of simultaneously affecting factors leading to the development of the disease.

Of the mechanical aspects, some trauma is considered significant. Even Kienböck (1910) argued that the disease is caused by wrist contusion or distortion, resulting in ligament damage resulting in disturbance of blood supply to the lunate. Similar evidence has been obtained from therapeutic studies in which a history of trauma is present in many reports in about half the patients, although much lower frequencies have also been reported (Irisarri 2004). The disease is more common in men doing manual labor, which has also been considered traumatic

etiology. Repetitive exercise and so-called microtraumas have also been implicated in the onset of the disease, but no clear evidence has been obtained (Gemne and Saraste 1987, Stahl et al. 2012). Stress fracture would result in disturbance to the venous blood supply, bone edema and ischemia, which, in the course of its progress, would cause osteonecrosis (Bain et al. 2016). Trabecular fractures lead to an "avascular fault plate" that can self-heal or recur, often leading to osteonecrosis (Watson and Guidera 1997). Probably trauma is a contributing factor in a situation where the circulation of the lunate is already disturbed. In dislocations of the lunate no descriptions exist of any changes associated with lunatomalacia. Spastic paresis involves lunatomalacia changes in 4.5% of patients (Joji et al. 1993). The explanation may be possibly related to fatigue microtraumas and ulna minus variance. In other similar data, lunatomalacia was found in up to 9.4% of patients (Rooker and Goodfellow 1977). In connection of primary fracture of the lunate avascular necrosis is rare (Teisen and Hjarbaek 1988).

2.3.3.1. Lunate shape variants and ulna-variance

Antuna-Zapico (1966) presented the above mentioned three lunate variants, of which type I is associated with the ulna minus variance. The other two are typical in ulna-neutral and -plus variances. In this material, type I existed in 30%, and the lunate`s trabecular structure was mechanically weaker than in the other two in 50% and 20% of patients (Owers et al. 2010). Type I constituted a risk group. According to Rhee et al., the lunate`s joining to the hamate (medial facet) appears to cause increased severity of the disease (Rhee et al., 2015), so that in the absence of the medial facet, the severity of the disease is higher, and there occur more fractures. It is not known whether the medial facet is of importance as an etiologic factor. Factors affecting the wrist mechanics, such as a carpal coalition (capitohamate) may possibly have etiologic significance (Cowan and Panattoni 2016).

Ulna minus variance, that is, a situation where ulna is shorter than radius, has been regarded as one of the etiologic factors of lunatomalacia after Hultén (Hultén 1928). It has occurred in 23 patients with lunatomalacia, 18 (78%) patients with minus variance, and 5 patients with neutral variance. In his study of normal population, minus variance was present in 23% and neutral variance in 51%. Similar results have been published in a number of patient studies (Steinhäuser and Merhof 1970, Afshar et al. 2012, Beckenbaugh et al. 1980, Lichtman et al. 1977, Sundberg and Lindscheid 1984, Bonzar et al. 1998, Gelberman et al. 1975, Mirabello et al.1987) On the other hand, some studies have shown no statistical correlation (D'Hoore et al .1994, DeSmet 1994, van Leeuwen et al. 2016, Chen and Shih 1990, Kristensen et al. 1986, Chung et al. 2001, Stahl et al. 2013). As an etiological factor, the minus variance of the ulna is not probable, meaning that correlation is usually apparent, but not causality.

It is also noteworthy that the ulnar variance is age-dependent (Sanderson et al. 1997), and racial differences have also been observed in American and Japanese series (Gelberman et al. 1975, Nakamura et al. 1991). Descriptions and measurement techniques can result in variations. For example, the effect of pronation and supination on a measurement result can be about 2 mm in one direction or another (Schuurman et al. 2001).

2.3.3.2. Blood circulation factors

Lunate arterial blood circulation has been investigated in vitro. Ståhl studied blood circulation with cadaveric veins using a stereoscopic X-ray technique with an intravascular contrast medium (Ståhl 1947). Dorsal vascularization could be seen in only 1/30 cases. Subsequently, studies have been carried out on Ward's blue latex with formalinization and sodium hypochlorite immersion using both micropaque injections and the Spalteholz technique (Gelberman et al. 1980). The results are somewhat divergent: 66% of the cases involved both the volar and dorsal artery, which were anastomosed within the bone; in 7.5% no anastomosis was found; and 26% had only a volar (15%) or dorsal (11%) arterial supply (Williams and Gelberman 1993). The lunate has an abundant volar and dorsal vascular plexus, and the external arterial damage is unlikely to be the cause of the circulatory disorder. Certain lunate bones dependent on only one arterial supply may put at risk a significant bone area, depending on the survival of the blood vessel. Changes in intraosseal blood circulation are more likely to occur in the initiation of the early stages of lunatomalacia, especially in the proximal part of the lunate bone, which is poorly vascularized. The risk of vascular interruption may be higher, if the lunate bone has only one intraosseal artery.

The rise of intra-osseal pressure as a result of venostasis is believed to be one of the etiological factors of lunatomalacia. Ten patients with lunatomalacia had a significant increase in intra-osseal pressure compared to the pressure of the capitate and the radial styloid (Jensen 1993). Further studies compared intra-osseal pressure of lunatomalacia patients to that of the normal lunate and capitate. In a 60-degree wrist extension, the pressure increased significantly in malacia patients. On this basis, the problem of venous circulation was suspected as a possible root cause (Schiltenwolf et al. 1996). A possible etiology is also the initial synovial disease, which would cause a circulatory problem (Irisarri 2004).

Individual factors related to lunatomalacia have been published, among others, sickle cell disease, corticosteroid therapy, as well as Crohns disease, SLE, scleroderma, and Raynaud sydrome (Irisarri 2004). A possible etiologic mechanism would be that inflammatory factors (cytokines) lead to local vasculitis and coagulopathy and circulatory disorder.

The etiology is still unclear, and possibly the disease is caused by a combination of many factors.

2.4. PATHOGENESIS

The disease picture and flow correspond to those of avascular necrosis found in other bones. It has not been shown, if there are possibly recurring ischemia stages like in hip joint in the initial phase. The lunate has edema in imaging studies. As the disease progresses, the osteoid tissue is replaced by granulation tissue. Osteoclast activity has been considered as a sign that there is still a blood supply in the bone. At the same time, new bone and sclerosis are produced as a result of osteoblasts. The so-called reforming zone has new bone, granulation tissue, and neovascularization. Bone stiffness loss leads to microfractures in trabecular structures, and the bone structure may fail most typically proximally and radially. In this case, a fracture of the lunate occurs in about 75% of cases (Beckenbaugh et al. 1980). Progressive changes occur such as linear compression fracture, diffuse sclerosis, cystic bone changes, and ultimately lunate collapse (Lutsky and Beredjiklian 2012). This in turn leads to collapse of the wrist and arthritic changes (Ueba et al. 2013). As a result of lunate collapse, the scaphoid rotates to flexion, whereby the pressure on the lunate increases. The development of the disease may sometimes stop or be very slow, years long. Typically, patients have had long-standing symptoms prior to the correct diagnosis (Beredjiklian 2009). The development of lunate collapse may take 1-2 years and the development of arthrosis 10-20 years (Martini 1990). It is generally considered that Kienböck's disease is progressive and leads to degenerative changes of varying degrees of severity in the wrist.

The disease may in individual cases afflict both wrists. Yazaci et al. (2005) published on 11 patients (251-patient series, 4.3%). There was no explanatory difference in radiological parameters. Taniguchi and Tamaki published 5 cases, 2 of which had autoimmune disease and took corticosteroid medication (1998). Morgan and McCueIII (1983) published a case report of 2 patients. In children, the course of the disease differs from that of adult disease. The prognosis of infantile (under 12 years of age) is usually always good. Among juveniles, healing varies, especially if the age is over 15 years (Irisarri et al. 2010). The infantile form accounts for about 1% of the reported cases, and in some publications the disease has been considered to be non-adult and often etiologically associated with exertion (Cvitanich and Solomons 2004).

2.5. DISEASE CLASSIFICATION

The classifications aim to clarify the degree of disease status and to establish a basis for evaluation and comparison of treatment outcomes. The classification is based on a X-ray image that should be standardized. In 1947, Folke Ståhl presented a classification which has served as a basis for later research (Ståhl 1947). In his dissertation, Ståhl considered lunate fracture as an etiologic factor of malacia. He presented 4 cases in which there occurred advanced lunatomalacia after a fracture. "The classification Group I included cases that have proven radiologically to be compression fractures of the lunate. Group II contains cases where the density line of the primary compression fracture has been replaced by a rarefaction line by secondary resorptive processes. Group III consists of those cases which, besides the changes mentioned above, exhibit in the neighborhood of the fracture line or the proximal portion of the lunate. Group IV is a collection of cases whose radiographs show fragmentation due to substantially vertical fracture or rarefaction lines or zones in addition to the previously mentioned changes. Group V consists of cases selected partly on account of a time factor and contains cases that showed their definitive form and structure already on first examination. They are sequelae."

New versions have since been developed based on this Ståhl rating. Decoulx et al. (1957) presented a classification, and based on that, Lichtman et al. (1977) presented the currently used classification. For this classification in stage I, the X-ray is normal, or may have a linear or compression fracture. In stage II, the density changes are obvious compared to other wrist bones, but the size and shape of the lunate compared to the other wrist bones is normal. On the radial side of the PA-picture, the height of the lunate may be reduced. In stage III, the entire lunate has collapsed, the capitate migrates proximally, and signs of scapholunar dissociation are also seen in the lateral view. In stage IV, in wrists occur degenerative changes, narrowing of joint spaces, subchondral sclerosis, and degenerative cysts. In 1993, Lichtman and Degnan (1993) supplemented the classification (Table 1). At stage I, the radiograph is normal, there may be a linear or compression fracture that is visible in tomography (Figure 1). Scintigraphy (bone scan) is usually abnormal, and MRI is (currently) diagnostic. Stage II as above (Figure 2), stage III described by collapse, scaphoid shortening (ring sign), scapholunar dissociation, and the triquetrum may have ulnar translation. The carpal height ratio (Youm et al. 1978) or the Ståhl index is changed (Ståhl 1947). The stage was divided into IIIA (Figure 3) and IIIB (Figure 4), where the scaphoid has fixed rotation. In stage IV generalized carpal degeneration is noted (Figure 5).

Table 1. Radiologic staging of Kienböck´s disease (Lichtman DM, Degnan GG. 1993)

Stage I	Radiographs normal. Linear or compression fracture possible. (MRI +)
Stage II	Definite increased bone density localized to the lunate. Some height may be lost on the radial side of the lunate.
Stage IIIA	The lunate has collapsed, and the capitate begins to migrate proximally.
Stage IIIB	Lunate collapse with fixed scaphoid rotation and other secondary derangements.
Stage IV	Lunate collapse and generalized carpal degeneration.

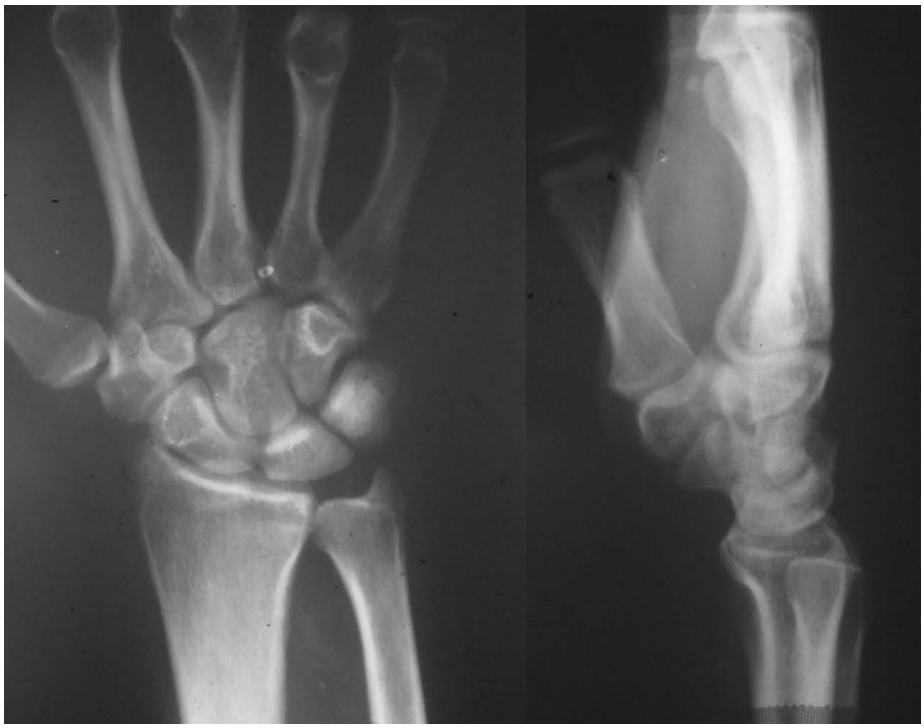

Figure 1. Kienböck's disease, stage I.
Right dominant wrist of a 22-year-old man, 1962, with form and structure of the lunate appearing normal. At follow-up, the lunate became deformed, the final image of which appears in Figure 5.

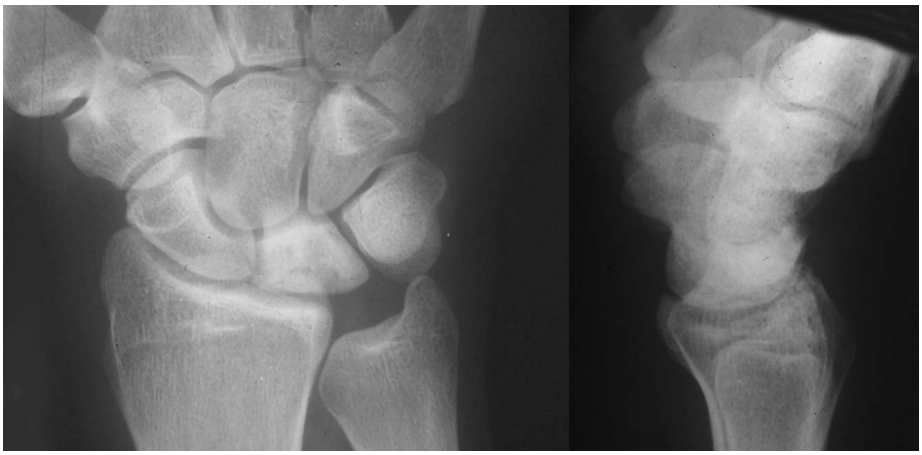

Figure 2. Kienböck's disease, stage II
The dominant wrist of a 26-year-old man. Note the fissure in the lunate, but no deformity. Ulnar variance -5 mm.

Figure 3. Kienböck's disease, stage IIIA.
The lunate bone is deformed. The radioscaphoid angle (RSA) is 58°, no arthritic changes.

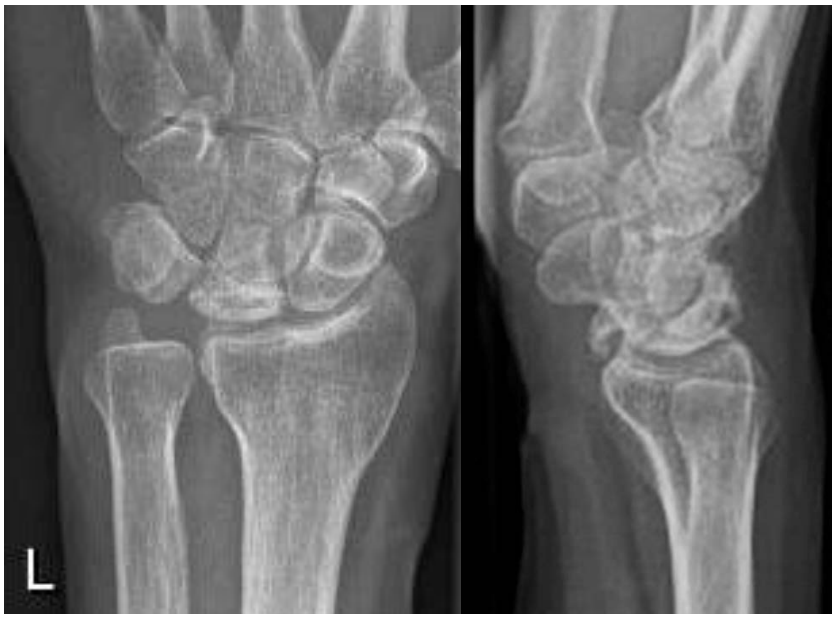

Figure 4. Kienböck's disease, stage IIIB.
The lunate bone is deformed, volarly fragmented, and collapsed (Ståhl index 17). Carpal collapse is visible, carpal height ratio (CHR) 0.43, and radioscaphoid angle (RSA) 60°, scapholunar angle (SLA) 54°. Ulnar variance -1mm, no arthrosis.

Figure 5. Kienböck's disease, stage IV.
The same patient as in Figure 1 after 51 years, treated conservatively. The wrist is arthrotic (arthrosis index 8/15) and the lunate deformed (Ståhl index 30). The patient is painfree at rest but has pain on strain (VAS 4.6). Wrist motion is 76% and grip strength 92% of the healthy side. DASH 13.3. He was able to work as a painter until age 58.

Goldfarb et al. (2003) investigated the relevance of the Lichtman classification in 39 patients. The radioscaphoid angle 60° and 8 other radiological parameters were taken into account in the radiological parameters. Observing the radioscaphoid angle raised the reliability of the Lichtman rating (kappa 0.81) and IIIA (kappa 0.75) interobserver reliability, ie. the reliability of the evaluation improved. No other radiological parameters showed significant differences.

Since then, classification has still been updated (Lichtman et al. 2010). In addition to the above-mentioned changes in stage I, the signal intensity in T1 and T2 is recorded as a MRI detection. The increase in T2 intensity means edema in the early stages of the disease, and later on, revascularization. To stage III has been added in IIIA stage an radioscaphoid angle of less than 60° and in the IIIB stage over 60°. Saunders and Lichtman (2011) have discussed the topic, especially in the initial phase of the disease, Stage 0, whose diagnostics and assessment emphasize gadolinium-MRI diagnostics. This can serve in the initial phase to assess whether it is edema or partial or total necrosis.

Schmitt et al. (1997) found that in the CT study, 67% of cases were higher in the stage compared to conventional X-ray imaging. The researchers determined MRI changes in different phases of lunatomalacia (Schmitt et al. 1998). In Stage I, diagnostics are based on MRI findings. Martini and Schiltenwolf (1998) presented their classification, which largely corresponds to the above. Quenzer et al. (1997) found that trispiral tomography, especially in stage I-II, increases the percentage of fractures and raises the stage in 73% of patients. In total, in their 105 patients, 91% of Kienböck patients had lunate fractures. Stahl et al. (2014) also presented their results which confirmed that the fragmentation of the lunate happens much earlier than before has thought based on plain radiographs.

In Bain's classification (Bain and Begg 2006), arthroscopy has served to grade cartilage damage, and therapeutic recommendations are based on this. The classification is grade 0-4, where in the grade 0 situation the cartilages of all the joint surfaces are intact, and in grade 4 the articular surfaces of the capitate, proximal, and distal surfaces of the lunate, and of the lunate fossa of the radius (four nonfunctional articular surfaces) are damaged. Grade 2b has a frontal fracture in the lunate. This Grade 2b is same as stage IIIC rating in Lichtmans new classification. Its recovery forecast is poor (Lichtman et al. 2010).

Lichtman's classification (Lichtman and Degnan 1993) is commonly used in Kienböck's disease studies. Goeminne et al. (2010) found in a study of 70 Kienböck patients with roentgenograms, 78% uniformity of the findings between different observations concerning classification rating, and between the researchers, kappa was 0.81, which means that the classification had good reproducibility and reliability. Jafarnia et al. (2000) found almost the same result, substantial reliability and reproducibility in the Lichtman classification. Goldfarb et al. (2003)

noted excellent interobserver reliability when the above-mentioned 60-degree radioscahoid angle criterion was used in the IIIB classification. Worse results have been reported, as well (Shin et al. 2011, Jensen et al. 1996).

2.6. CLINICAL EXAMINATION

The symptoms of Kienböck's disease may vary considerably in the early stages. The symptoms may be intermittent, with a slight exacerbation associated with stress. Swelling and synovial signs may appear in the wrist, the range of motion decreases, and the grip force worsens due to the wrist pain. This condition can be considered as due to tendon inflammation, because no findings specific to the disease are present. Some patients have, before symptom onset, a wrist injury, which may be mild, but the disease can often occur without any prior injury. In children and adolescents, the disease is rare as well as in the elderly, over 60 years of age. Kienböck's disease is sometimes associated with carpal tunnel syndrome (4%, Beckenbaugh et al. 1980), and individual tendon ruptures (FPL) have been described.

Based on data from the 86 published articles, the average age of patients was 33.3 (25-53.4) years at surgery. Patients had age ranges from 10 to 72 years. Fourteen articles included a pre-treatment symptom period ranging between 4.9 months and 9.2 years with an average of 29.7 months. The men comprised 70.9% (n = 74; 1350) and women 29.1% (n = 74; 554). Lunatomalacia occurred in the dominant hand in 66.8% (n = 44) and the right / left ratio was 2.1: 1. Trauma was mentioned in 12 articles as part of patient histories, in those publications applicable to 43% (14.3-63.6%) of patients. The results are collected from source literature.

The data correspond to the general perception of the occurrence of the disease. Kienböck disease occurs most commonly in young people of working age, age 20-40, males and the right-side-dominant disease (Beredjiklian 2009, Lutsky and Beredjiklian 2012). In their article, Szabo and Greenspan (1993) mention the disease predominantly in men at a ratio of 3:1, with a top incidence between 18 and 40 years of age. Regardless of sex, 95% of these patients were performing heavy hand-labor.

2.6.1. Range of motion, ROM

In the diagnosis phase of the disease, the movement of the wrist is usually limited in all directions, flexion limited the most. This phenomenon is explained by the wrist synovitis and the fact that lunatomalacia often is already at stage III at the diagnosis phase. The wrist ROM is measured using an angle meter to measure

extension, flexion, and radial and ulnar deviation when the forearm is in pronation. The prosupination measurement is performed with the arm in adduction, and at a 90-degree angle with the elbow (Solonen and Nummi 2012). For comparison of ROM, the contralateral (healthy) wrist ROM is measured, too.

2.6.2. Pain

Pain is the patient's most significant and most common symptom. Lunatomalacia may sometimes be painless, and the findings may appear coincidentally when imaged for other reasons, although that situation may be unusual. In lunatomalacia, pain may exist at rest, and exertion usually exacerbates the symptoms. Mennen and Sithebe (2009) wrote in their article about the importance of the cultural and therapeutic environment in patient's attitudes towards their symptoms and, on the other hand, the impact of healthcare provision in the seeking of treatment. In Western countries, it is likely that patients will be quite sensitive to the symptoms and will be covered by the treatment.

Pain is evaluated by a VAS (visual analogue scale) scale of 0 to 10, where 0 means a painless condition and 10 the worst imaginable pain. The patient marks the pain intensity by a crossbar (Flaherty 1996). The method was already presented by 1972, and it has been commonly used—and almost exclusively in addition to the patient's verbal estimate, when presenting Kienböck's treatment outcomes. Due to the retrospective nature of the studies, the estimations of initial or pre-treatment status are rather limited or have been made afterward. Other pain assessment methods are the verbal evaluation used in several publications.

Grip strength is affected by pain and long-term uselessness and handedness. In general, the publications have indicated the type of measurement that has been used and whether the value obtained is the maximum or the average of three measurements. The comparison is used on the healthy side of the measured value, in some cases being statistical averages. Dominance can be taken into account when compared to the healthy side, wherein the force of the dominant side is approximately 10% greater in a normal situation. The force of the pinch grip is not included in most publications.

2.6.3. Function

Functioning is an essential part of patient performance in daily activities and work. Scoring systems have been developed for the evaluation, which take versatile hand and upper extremity functions into account.

2.6.3.1. Subjective estimates

The most commonly used is the questionnaire for Disability of the Arm, Shoulder and Hand (DASH), originally developed by the American Academy of Orthopedic Surgeons and Institute for Work & Health (Amadio 1997). This questionnaire has 30 questions asking about the capability of the patient's upper limb during the week preceding the survey. The survey contains the assessment of pain and disability in everyday life (1-5 scale) in 21 items. Five items discuss the intensity of pain and discomfort in the upper limb and four items the effect of discomfort on daily life, sleep quality, and self-esteem (Hacklin et al 2009). In addition, the questionnaire has two optional parts, a work section and a sports / music section, each containing four questions. For all points, an average is calculated, one point subtracted from each and multiplied by 25. The final result is between 0 and 100, the larger it is, the greater the disadvantage. There is also an abbreviated version of the DASH scale with 11 questions and an optional section as above (QuickDASH). Both are used as a curve of results. In Finnish, DASH was validated in 2008 (Hacklin et al. 2009) and approved by the Institute of Work & Health on December 11, 2008.

DASH is validated and is currently in the public domain. It gives a picture of subjective constraints, with less significance of activity and metrics (Birch et al. 2011). Correlation of the DASH with pain is weak, which can limit its use, eg in wrist disorders. On the other hand, its reproducibility is good, and it measures very small changes in the patient's condition (Changulani et al. 2008). DASH is also "age-dependent." Aasheim and Finsen (2014) stated that 20 to 29-year-olds had an average DASH of 5, those 70-79 years of age of 22, and over 80 years old, of 36. AAOS has approved DASH as a standard for hand and upper extremity disability assessment. DASH has been extensively studied for reliability, reproducibility, validity, and responsiveness as well as for its acceptance in clinical practice (DeSmet 2007). In normal populations, the average DASH value is 10.1 (SD 14.88) (Hunsaker et al. 2002).

2.6.3.2. Wrist scorings

The PRWE score (Patient-Rated Wrist Evaluation questionnaire) (MacDermid et al. 1998) was initially devoloped for evaluation of radius fracture outcome. Pain and function share is equal and total scoring ranges from 0 to 150 (worst possible). Scoring validity was not considered good compared to the SF-36 score or impairment score (Changulani et al. 2008). In estimating the result of a distal radius fracture, the method proved to be reliable (MacDermid et al. 2000, Changulani et al. 2008). In Finnish, the test has been validated (Sandelin et al. 2016).

The Mayo Wrist Score (MWS) gives a maximum of 100 points, of which the pain ratio is 25, the active extension / flexion 25, the hand grip force in percentage of the contralateral side 25, and the ability to return to work or activities 25 points.

The result is estimated to be excellent (90-100), good (80-89), moderate (65-79), and poor (less than 65 points). The result is satisfied, if the score is ≥ 65 points (Cooney et al. 1987).

2.7. RADIOLOGY

2.7.1. X-ray imaging

The X-ray is still crucial to Kienböck's disease diagnosis, classification, and measurement of mechanical wrist alterations. The prerequisite for the evaluation of carpal bones is correct postero-anterior (PA) and lateral projections. In the PA X-ray, the shoulder joint is in 90° abduction and the elbow in 90° flexion, so that both joints are in the same plane. In the lateral projection, the upper arm is in adduction, elbow in 90° flexion and forearm in a neutral position; the wrist is in a neutral position (no radial or ulnar deviation, no flexion or extension). In the PA picture of the wrist, the ECU groove must be in the right place and in lateral view, the palmar surface of the pisiform at the midpoint between the palmar pole of scaphoid and palmar surface of the capitate head (Yin et al. 1996). From the X-ray images can be determined the stage of the disease previously described.

The classification of Kienböck's disease was originally based on X-ray imaging, which is still a basic examination, due to its availability. Repeatability and relevance vary with radiological landmarks at 2 degrees intervals, in the digitized image, 0.1 mm and 0.4 degrees (Barantz and Larsen 1996).

As Kienböck's disease progresses in the lunate, compression occurs, the height of the wrist is diminished, and ulnar translation is generated. The lunate`s covering ratio changes, while the proportion of lunate jointing to the radius decreases. In the side view, when the wrist is lowered, the scaphoideum rotates to flexion. Measurement of the scapholunar angle is often difficult when the lunate is fragmented, and therefore the radioscaphoidal angle measurement is used with the boundary between the IIIA and IIIB being 60° (Goldfarb et al. 2003). At the same time, the triquetrum rotates to the extension. It is about adaptation of the wrist after lunate compression, and this is generally not related to damage to the scapholunar ligament (Taniguchi et al. 2002). Lunate compression is also measured from lateral images. As arthrosis develops, the disease will progress to stage IV, and changes may occur in the radiocarpal, midcarpal, and intercarpal joints.

The measurement of the lunate compression (Ståhl index) is done in the lateral view, and the result is expressed as the ratio of longitudinal (sagittal) height to the dorsopalmar measure. The average value is ≥ 50 (Ståhl 1947)

2.7.1.1. Wrist collapse

The height of the wrist is measured from the basis of metacarpal III to the radial distal joint surface. The carpal height ratio is the ratio of the carpal height to the third metacarpal length, averaging 0.54 (SD 0.03) (Youm et al. 1978) or 0.53 (Schuind et al. 1992). The reference is the healthy wrist. The height index of the wrist can also be expressed in relation of the carpal height to the length of the capitate with a normal value of 1.57 (SD 0.05) (Nattrass et al. 1994). Ulnar translation is usually mild and associated with lunate deformation. There are several methods of measurement (Barantz and Larsen 1996), and perhaps the most commonly used is presented by Youm et al. (1978). It measures the distance between the center of the capitate and the mid-length axis of the ulna (carpoulnar distance) divided by the length of metacarpal III. The normal CUDR is 0.30 (SD 0.03) (Figure 6).

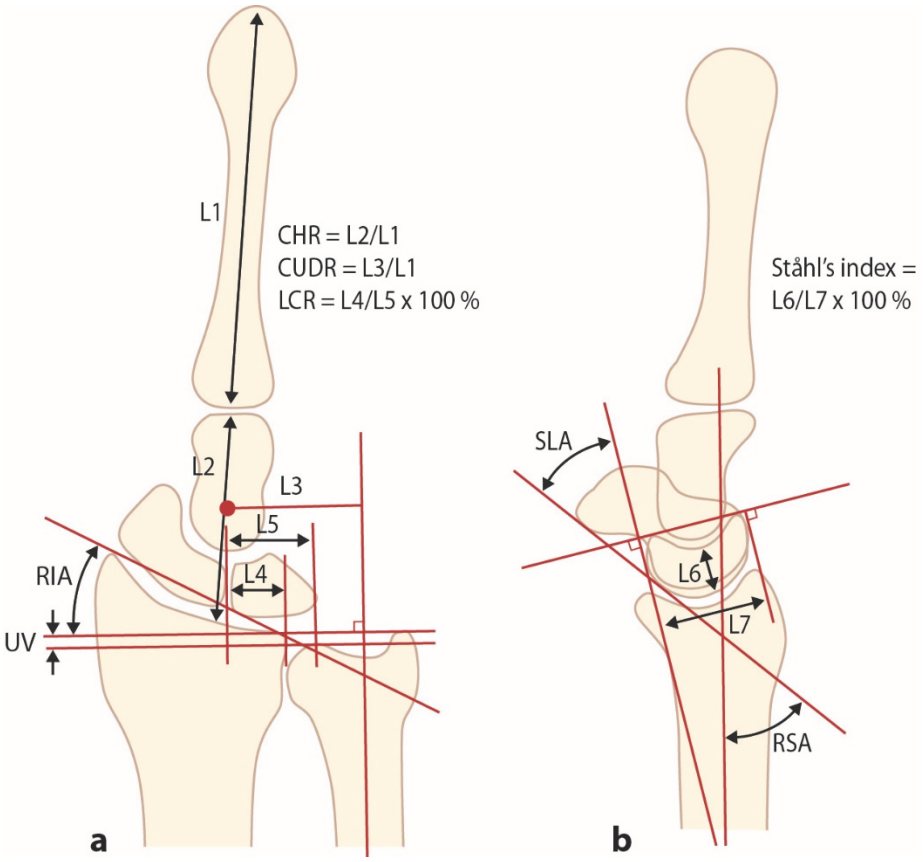

Figure 6. Carpal indexes
(Wada et al. 2002). Fig. 6a. Carpal height ratio (CHR), L2/L1 (L1 = length of metacarpal III, L2 = height of carpus) 0.54 (SD 0.03)*. Carpal ulnar distance ratio (CUDR) L3/L1 (L3 = distance from midpoint of the capitate to midline of ulna), 0.30 (SD 0.03)*. Lunate-covering ratio, L4/L5, the proportion of the lunate corresponding to the radius, as a percentage. UV, measurement of ulnar variance according to Gelberman et al. 1975. RIA, radial inclination angle. *Youm et al. 1978.
Fig. 6b. Scapholunar angle (SLA) and radioscaphoidal angle (RSA). Measurement of Ståhl index, relation of height to breadth of the lunate as a percentage. Normal value ≥ 50 (Ståhl 1947).

2.7.1.2. Evaluation of arthrosis

Kienböck's disease publications generally do not interfere with the classification of arthrosis. Knirk and Jupiter (1986) presented a grading scale in which grade 0 was normal, grade 1 mild joint space narrowing, grade 2 that + osteophytes, and grade 3, with severe narrowing of the joint space, edge osteophytes, and bone cysts. Wollstein et al. (2012) categorized wrist arthrosis into grades 1-4 as follows: grade 1 arthrotic changes between the scaphoid and radial styloid, grade 2 arthrosis between the scaphoid and the scaphoidal fossa of the radius, grade 3 arthrosis additionally in the lunocapitate joint, and grade 4 arthrosis additionally in the radiolunar joint or "panarthritis" changes.

2.7.1.3. Evaluation of ulnar variance

The ulnar variance is measured from the PA image with the forearm in a neutral position. Gelberman's method (Gelberman et al. 1975) is performed on projections, one of which is from the ulnar distal joint surface of the radius and the other from the distal joint surface of the ulna. The difference is measured in millimeters (Figure 6). The Palmer method uses a template with a millimeter scale (Palmer et al. 1982). Kristensen et al. (1986) still modified this method by using the center of the radioulnar joint as an auxiliary point for circular measurement. A measurement accuracy of ±2 mm has been considered significant.

Minus variance is often found in Kienböck's disease. Steinhäuser and Merhof (1970) found a minus variance in 57.5% of patients, neutral variance in 40%, and plus variance in 2.5%. In a series of 1095 normal wrists, minus variance was found in 16.6%, neutral in 71%, and plus variance in 12.3%. In the aforementioned Hultén series (1928), no plus variance at all was apparent in Kienböck's disease. De Smet (1994) found that ulnar variance was associated with age, genetics, strain, and the pathology of the elbow. He did not keep the minus variance as an etiologic factor for Kienböck's disease. Reaching the same conclusion also was Kristenssen et al. (1986), D'Hoore et al. (1994), and Stahl et al. (2013). Chen and Shih (1990) compared 1000 normal wrists to 16 lunatomalacia wrists. The average variance was 0.313 in the normal population and -1.222 mm in lunatomalacia. Significant variance (-2 mm or more) occurred in 6% in the normal group and in 55.6% in the patient group. The conclusion was that, in Kienböck's disease, a minus variance of the ulna is predisposing but is not a causal factor.

2.7.2. Magnetic resonance imaging, MRI and other imaging modalities

Early diagnosis of Kienböck's disease is relevant if the belief is that it is accepted that therapeutic measures can influence the course of the disease. The sensitivity and specificity of MRI in the evaluation of avascular necrosis is excellent, and

magnetic research is the most important in avascular bone- imaging diagnostics. Usually, the many sequences used include T1W, PD, T2W, SE, and fat-suppression, as well as thin-cut 3D images (Reinus et al. 1986). A surface coil with 2- to 3-mm cut thickness and intravenous enhancement (gadolium; gadopentate 0.1-0.2 mmol / kg body weight) is recommended (Schmitt et al. 1997). Fat-suppression images are taken before the gadolium. The MRI is relevant at the beginning of the disease and possibly also at the IIIA stage in the assessment of residual perfusion and in the monitoring of healing.

In its early stage I, ischemia leads to edema of the bone marrow, reducing the signal in the T1-weighted sequence, but increases it in the T2-weighted one, with perfusion being retained. The MRI also indicates a possible focal region where T1 intensity is decreased and T2 intensity varies parallel with the partial enhancement of the lunate by gadolinium. Stage II may have a heterogenous signal structure, after the enhancement of the region under repair, and the locally vital distal portion of the lunate, although the proximal lunate is necrotic. There is evident no enhancement at Stage III, indicating advanced disease with total necrosis of the lunate (Schmitt et al. 1997, Arnaiz et al. 2014).

A CT study best describes bone anatomy and the exact degree of disease, especially at Stage II. In 65% of the CT, it can become a higher stage than in conventional radiograph. Pseudocystic changes and sclerosis of porous bone, occult shell-shaped fractures of the proximal pole, as well as perilunar arthritis can be found earlier and can be more widespread (Schmitt et al. 1997). Three-phase scintigraphy was used earlier in early diagnostics (Nägele et al. 1990), but nowadays, magnetic resonance imaging has largely replaced scintigraphy.

2.8. DIFFERENTIAL DIAGNOSIS OF KIENBÖCK`S DISEASE

Diagnosis of lunatomalacia is mainly based on X-ray- and MR studies. In differential diagnostics particularly MRI is a valuable tool.

A. Acute fracture or lunate contusion may be difficult to distinguish from stage I malacia. In MRI or CT, a fracture line may appear. In T1, the line is hypointensive, and the T2 image may have diffuse hyperintensity. A history of trauma is an important tip (Arnaiz et al. 2014).

B. Ulnar impaction syndrome: the MRI change in the lunate is in the ulnar side. In addition, there often appear degenerative changes in the TFCC and in the capitulum ulnae, whereas in X-ray, in addition to the positive ulnar variance, there are often sclerosis and cystic changes.

C. Rheumatoid arthritis, gout, and degenerative or post-traumatic arthritis: changes are often wider and are not limited to the lunate.

D. Lunate intra-osseal ganglion, often located on the radial side and communicating into the joint space. Mucous degeneration gives a typical cystic finding in MRI. The so called miniganglions, which are common in youg patients, are also diagnosed with MRI or ultrasound examinations.

E. A bone island appears as a sclerotic change in X-ray. Low intensity in T1 and T2 images can be obtained.

F. Tumors such as an osteoid osteoma are very rare in the lunate.

2.9. NATURAL COURSE OF LUNATOMALACIA

The natural course of lunatomalacia remains unclear. No reliable studies concern the matter, except for a small number of individual studies with few patients. This is not surprising concerning the rarity of this disease. No controlled prospective multi-center studies exist. Patient's inactive treatment and follow-up without action may also be an unacceptable alternative from the patient's viewpoint, at least this issue would require thorough information.

The duration of the initial phase of the disease is unknown. On its duration affects, among other things, the variability of early symptoms of the disease, the timing of the seeking of treatment, and possible diagnostic delay. Some patients may be asymptomatic or have few symptoms for a long time, and often in the diagnostic phase, the disease has progressed to stage III. Martini (1990) studied the pathway of the disease in non-operative lunatomalacia patients based on X-rays. In stages I and II, remission is possible, and the length of stage I may range from 4 to 35 months after diagnosis has been resolved. Stage III was found on average 20 months after the onset of symptoms that have lasted from 8 months to 6 years. The interval between stage IIIA and B was 6-14 months. The collapse phase may take 2 to 20 years before significant arthrosis occurs. New techniques, high resolution MRI and ultra-thin section CT, give perhaps more information about natural course of the Kienböck's disease (Stahl et al. 2014).

Possibly the disease progresses in a different way in different patients. This affects the evaluation of treatment outcomes, especially if the follow-up times are short. The course of the disease may look different if changes are evaluated by other methods, such as by arthroscopy (Bain and Begg 2006).

Only a little information exists as to the natural course of lunatomalacia. Beckenbaugh et al. (1980) published on a series of 46 lunatomalacias. Of these, 10 had mild symptoms that were not actively treated. The follow-up period was 7 years. On average, the extension was 46 and flexion 43 degrees, the grip force 59% of the healthy hand. The pain was gradually alleviated, but wrist movements were restricted. Moderate grip force reduction was not a big problem, and all patients were able to work in their former job. There was a progressive change in X-ray images, but with no symptoms worsening. When compared to the surgical treatment of both groups, their pain relief and function were at the same good level. Unfortunately, that study does not describe the starting position of either group more precisely.

In their retrospective study, Kristensen et al. (1986) compared 22 patients, treated with an average of 8 weeks of immobilization as one patient group, to a group of 24 untreated patients with follow-up averages of 23 and 18.2 years (Table 2). Of those treated, 83% were without pain or reported pain only during heavy work, and 77% of those untreated. In X-rays, none of the lunates had become better or less deformed than in the initial situation. These researchers noted that the lunates were deformed when the patients began treatment, which explains the poor power of conservative treatment. Immobilization could prove useful in a situation where deformation has not yet evolved. The researchers conclude that Kienböck's disease is inherently benign, the symptoms arising mainly through arthrosis being present in 85%, and immobilization provided no advantages.

Fujisawa et al. (1996) published 17 patient records with an average follow-up of 15.6 (10-28) years, of whom, 12 patients wore a splint for an average of 5.4 months. Five of these wore splint 1-2 (mean 1.5) months and five patients were treated only with painkillers. Of these 10 (Table 2), 5 were farmers, 2 were labours and 3 white-collar employees. The duration of the symptoms had been 10.9 months (1 month to 4 years). Lichtman stage was II for one, III for 5 and IV with three. At follow-up, two were stage II and two stage III, the others IV. The follow-up time for these group of 10 patients with lunatomalacia was 15 (10-21) years. The flexion was an average of 49° and an extension of 47°. The Ståhl index was on average 34 in the beginning and 30.5 at follow-up. The end result on the Evans evaluation scale (the criteria being roughly the same as in MWS) was five being good, three moderate and two being poor. The researchers did not evaluate separately the outcome of the untreated.

The natural course of lunatomalacia has not been fully estimated because in the retrospective studies of Beckenbaugh and Kristensen, its initial state has not been unequivocally clarified. Fujisawa followed only five non-treated patients. During the follow-up period, their disease progressed. For natural-course groups, the patients can easily be selected only mild lunatomalacia cases causing selection bias.

Lunatomalacia progresses in untreated patients; treatment results are, however, satisfactory when compared to such treatment as silicone-implant arthroplasty (Beckenbaugh et al. 1980) or immobilization (Kristensen et al. 1986).

2.10. CONSERVATIVE TREATMENT

In individual cases, demarcation between conservative treatment and the natural course may be unclear, because conservative treatment may include, splint care if necessary, if for instance necessary at night, and authors have made no specific clarifications. Patients may also opt to leave immobilization, according their own consideration. In addition to immobilization (plaster cast immobilization or splint), conservative treatment often involves stress avoidance, sick-leave, and, if necessary, pain medication. Medication use is rarely recorded. Work ability and quality of work or level of stress are included in many estimates. Examples of such borderline cases are three so-called "almost natural course" articles (Delaere et al. 1998, Keith et al. 2004, Van den Dungen et al. 2006).

Delaere et al. (1998) compared in their retrospective study 21 patients (22 wrists) receiving conservative treatment with 20 patients (21 wrists) after operative treatment of lunatomalacia. Conservative treatment included the use of a wrist splinting at night during painful periods. The operative treatment was heterogeneous, comprising three revascularizations, one of these having later STT fusion, 11 STT fusions, and 6 PRCs, as well as one radial shortening- and one ulnar lengthening osteotomy. In the conservative group, four patients had had a carpal-tunnel release, which was not considered to be a treatment for lunatomalacia. The publication does not show how the patient groups were collected. They were fairly homogeneous and comparable as to all clinical data and ulnar variance. Stage I-II disease occurred more often in the conservative treatment group. The follow-up time for the conservative group was 65 months and for the operated 66 months. No difference emerged between the results in terms of pain, grip strength, or radiology, or in patient's subjective satisfaction. Wrist motion was worse in the operated group, probably due to STT fusion. Those conservatively managed managed in work and leisure activities better. Researchers think that these results support the conservative care and careful selection of surgical management indications.

Keith et al. (2004) retrospectively investigated 33 lunatomalacia patients after a symptom duration of 8.1 (1-38) years. Conservative treatment included varying degrees of immobilization, splint use, and physiotherapy. Length of follow-up did not affect the pain as assessed on the VAS scale, but the DASH value decreased as both tracking time and stage increased. The authors consider this situation to be

a sign of deterioration. Moreover, flexion and grip strength decreased when stage deteriorated. In short, the disease does progress over time.

Van den Dungen et al. (2006) compared conservative treatment and STT arthrodesis (Table 2 and 5). Of the 104 patients, 59 were conservatively treated with a night splint during pain periods, and some had used an orthosis during heavy work. Only 19 patients attended the follow-up examination; 25 were treated with STT fusion, of them 11 participated in the study. The conservative group`s follow-up time was 12 (7-18) years and that of the operated group 14 (6-18) years. In the surgery group, barometer pain was more common, and the length of work disability was 120 days, in the conservative group 18 and DASH score was a respective 21 and 17. In both groups, stage rose, in 10 in the conservative group, of which half were at stage IV, and in 7 in the operative group, of which 6 were at Stage IV. In summary, STT arthrodesis did not improve clinical outcome or failed to prevent radiological deterioration. After conservative treatment, the radiological changes did not correlate with clinical outcome. Conservative treatment was considered a possible alternative.

Based on these three articles, no conclusions can be drawn as to the natural course of the disease.

It is obvious that the course of the disease varies. In the early stages of disease improvement, even recovery is possible (Martini 1990). Often the symptoms appear and worsen when the lunate collapses and gradually calm down when the wrist becomes adapted to its new order. The patient's function also adjusts to the performance level set by the wrist, and the symptoms are tolerated.

Ståhl (1947) presented in his dissertation On Lunatomalacia (Kienböck's disease) the classification of lunatomalacia, which has been the basis for the Decoulx (Decoulx et al. 1957) and Lichtman classifications later (Lichtman et al. 1977). He also developed an index representing the compression of the lunate, which is usually somewhat over 50, the lunate "compression quotient," which describes the relationship between the indexes of the healthy side and the diseased side being always less than 1 (Ståhl 1947). In his retrospective follow-up study of 132 patients, 40 patients had been treated for their symptoms with short-term splinting, and 86 with plaster immobilization. The average follow-up time was 11 years (the median 11.5 years). Four of the patients were group I (thought to have been caused by a recent compression fracture), II 6, III 59, IV 44, and group V (final condition) 19 wrists. At follow-up, 31 were asymptomatic. The rest had varying degrees of symptoms, and 13 had changed their jobs due to the wrist disorder. The results of I and II were the best. Functionally good results occurred in 50% and poor in 10%, group III 33.9% / 23.8% and IV 4.5% / 40.9% and 21.1% / 42.1%, respectively. Results correlated with the duration of immobilization, so that results from less than 2 months of immobilization were worse than among those immobilized for

more than 2 months, and the best result was from being immobilized for more than 5 months. The result covered both clinical and radiological findings.

Subsequent studies with immobilization have not achieved similar results. Mikkelsen and Gelineck (1987) published on a 25-patient series. The treatment was a splint for 6 (1-24) months. The follow-up period was 8 (1-11) years. Five patients were treated with arthrodesis due to the wrist pain. Six patients were painless, nine had pain during light and five during heavy work. At the beginning of treatment, the disease level stage II for 7, stage III for 13, and stage IV for 5 patients. At follow-up, stage II had 3 patients, stage III, 3, and stage IV, 13, plus 5 with arthrodesis (stage IV). The result was not considered successful.

Kristensen et al. (1986), published 22 patients which were treated with a plaster splint or equivalent for an average of 8 (2-24) weeks, and 17 patients still used leather support during heavy work (Table 2). The follow-up period was 23 (8-32) years. In the follow-up study, 83% of patients were painfree or reported pain only with heavy work. In most patients, the pain had gradually been relieved over some years, irrespective of treatment or work. In the X-ray, all the lunates were deformed, more than in the initial stage, and none were normal; 8 (34.7%) had been broken. Many were painless despite deformation and fragmentation. There were 11 (48%) patients with arthrosis. No comparison to the initial situation could be made, because roentgenograms were missing for 13 patients. The researchers concluded that immobilization was not helpful, because the result did not differ from those of patients without treatment.

Fujisawa et al. (1996) monitored 20 patients for more than 10 years, and 17 of these unilateral subjects were included in the study with an average follow-up of 15.6 (10-28) years. 12 patients were treated with a splint averaging 5.4 (1-13) months. Five patients had only had pain killers. At follow-up, 9 patients were painfree, one had pain in cold weather, six mild discomfort in or after heavy work, and one had moderate pain. The wrist flexion was 25-75 degrees and extension 25-80 degrees. In only one patient was the flexion-extension 60 degrees or less. The grip strength was a mean 79.9 (30-100 %) of the strength of the healthy side. Evans' system estimates were: ten good, four moderate, and three poor; 14 had continued their former work, and three had changed their work due to their wrist. The initial Lichtman stage was I three, II three, III eight, and IV three. At follow-up, five were in the same category and eight had progression, but four were in the lower category: five stage II, five stage III and seven stage IV. Based on these results, the conclusion was that Kienböck's disease has the capacity to repair itself spontaneously, but the authors did not explicitly recommend conservative treatment. No treatment-group of these patients is presented in Table 2.

Salmon et al. (2000) compared 18 patients with conservative treatment to 15 patients who underwent radial shortening osteotomy. The conservative treatment

used went unmentioned. The average monitoring time was 3.6 (1.5 to 9) years. Operatively treated patients had less pain and better grip strength. Radiological progression when conservatively managed progressed more although the surgery did not completely block it either.

Evans et al. (1986) compared conservative treatment with silicone arthroplasty. Conservative treatment consisted of a block-leather wrist splint, which two-thirds of the patients used for 4 to 5 years, one patient wearing it from time to time for 20 years (Table 2). A plaster cast was used occasionally for some patients, and one received no special treatment. Patients numbered 14, wrists 16, and average follow-up time was 20 years. The silicone-arthroplasty group consisted of 21 wrists with a follow-up of an average of 5 years. The Lichtman stage in the conservative treatment group was initially: stage II 3 patients, stage III 6, and stage IV 3. At follow-up, one stage II proceeded to stage III and two from stage III to stage IV. Five wrists were painless, six had mild pain, and three had moderate. The Evans criterion was good for four, for six was moderate and for six was poor. None was very bad. Except for one patient, all returned to their former jobs. The results of silicone-arthroplasty were good for 9, moderate for 7 and for 5 were very bad. In this group, as well, more than half the patients had carpal collapse, scapholunar diastasis, and degenerative changes. Researchers concluded that conservative treatment outcomes were better than previously thought, with no radiological deterioration apparent. Attention is drawn to the fact that the conservative treatment group had one 14-year-old (bilateral) and one 15-year-old patient with good results. Silicone-arthroplasty gave a good result in short-term follow-up, but the result deteriorated due to the dislocation of seven implants. One patient experienced wrist arthrodesis.

Table 2. Long-term results (mean ≥ 10 years follow-up) of different treatment modalities in Kienböck's disease. Natural course and conservative treatment.

Authors	Year	N patients/ wrists	Treatment	Initial Lichtman stage I / I / IIIA / IIIB / IV	Follow-up time, years mean (min-max)	Pain VAS or presented numbers	Grip strength % of contralat.	ROM[1] ext/flex (°) or % of contralat.	DASH[2] mean (min-max)	MWS[3] mean (min-max)	Progression (in Lichtman stage),%	Arthrosis presence %
Kristensen et al.	1986	24/26	no	all deformed	18 (5-33)	no pain 8, in mild strain 6, in heavy strain 12	-	-	-	-	all deformed	85
Kristensen et al.	1986	22/23	conserv.	all deformed	23 (8-32)	no pain 7, in mild strain 4, in heavy strain 12	-	-	-	-	all deformed	48
Fujisawa et al.	1996	10	no	0 / 2 / 5 /- /- / 3	15 (10-21)	no pain 5, occasionally 2, constantly in use 3	78	47°/49°	-	-	40 (20% better)	60
Van den Dungen et al.	2006	19	conserv.	1 / 7 / 8 /- /- / 3	12 (7-18)	mechanical 11, occasionally 11, barometric 6, at rest or permanent 2	83	92°	20.7 (2-43)	-	53	42
Evans et al.	1986	14/16	conserv.	0 / 3 / 6 /- /- /3	20 (10-36)	no pain 5, mild 6, moderate 3	72	42°/36°	-	-	14 (no data 28%)	64

[1]Range of motion; [2]Disabilities of the Arm, Shoulder and Hand; [3]Mayo Wrist Score

Dornan (1949) published on a 43-patient series, in which 16 patients (37%) were treated with lunate excision and 27 (63%) conservatively with immobilization for 3 or 4 months. Two had no specific treatment, and two were treated with rest and physiotherapy. Surgery was targeted at young people, mostly under the age of 30, if there was no arthrosis. Heavy work was possible for 38 patients. Outcomes of conservative treatment were 9 (33%) excellent, 8 (30%) good, 7 (26%) moderate, and 3 (11%) poor. After surgery, the result was excellent in 7 (44%), good in 4 (25%), moderate in 4 (25%), and poor in one (6%) with later arthrodesis. Many patients in the conservative treatment group had had symptoms for a long time, and a new injury caused an exacerbation of symptoms. Immobilization often moderated / eased this situation. The follow-up time was not mentioned, but 60% of those conservatively treated and 69% of surgical patients returned to their former jobs.

Martin and Squire (2013) compared 44 non-surgically treated to 18 surgically treated lunatomalacia patients in their retrospective follow-up study. Patients were monitored for less than 5 years, for 5 to 10 years, and for over 10 years, with the DASH score. In the initial stage, 6 patients were in stage I, 26 in stage II, 9 in stage IIIA, 16 in stage IIIB, and 5 in stage IV. The surgical treatment included 11 partial and 5 total fusions, 1 excision and 1 RSO. In operatively managed patients, the stage was worse, with no more detailed description provided. The DASH score in all monitored groups was in those treated conservatively 20 (1.7-81) and in those operatively treated 23.7 (0.9-82.8). For the groups with follow-up of more than 10 years, it was a respective 14.7 for 15 and 23.8 for 9. The differences were not statistically significant. Age at diagnosis correlated positively with DASH, meaning that young people had a better outcome.

In the meta-analysis of Innes and Strauch (2010) various treatment methods were compared: vascular bone graft, metaphyseal core decompression, radial osteotomy (Lichtman I-IIIA, “early stages”), and partial arthrodesis, PRC, tendon ball arthroplasty, and nonsurgical treatment (Lichtman IIIB-IV, “late stages”). No difference emerged in treatment results for any group with pain. Movement improved significantly in radial osteotomy and vascular bone graft in early stages and in all groups, except for the partial arthrodesis and conservative treatment for late-stage patients. Grip strength improved significantly in early-stage group after osteotomy and vascular bone graft and for all late-stage patients except those managed conservatively. Carpal height ratio and the Ståhl index did not differ except in RSO in the “early” group.

Conservative treatment studies are quite heterogeneous and there exists no conclusive rationale. Immobilization is generally recommended as the primary and initial treatment of Lichtman Stages I-II. In some patients, remission is probably possible. According to Ståhl’s research, this immobilization recommendation also receives support. Immobilization of stage IV patients could be considered as one

treatment, based on the symptoms. Immobilization does not necessarily impede compression of the lunate and progression of the disease. There are no prospective follow-up studies.

A juvenile lunatomalacia is also generally treated conservatively. Its etiology is unclear, one of the possibilities being considered is an immunologic factor. The course of this disease differs from that of the adult disease. Children under the age of 12 (infant lunatomalacia) have a good prognosis and the lunate is usually restored normal or almost normal (Irisarri 2004, Irisarri et al. 2010). In young people aged 13 years of age and over, prognosis of the disease worsens year by year. Typically, the palmar angle of the lunate increases and VISI deformity is generated. Even if the lunate is not fragmented, the wrist is often painful and affected by synovitis. Some patients have suffered a wrist injury beforehand. Treatment is assessed according to the situation.

2.11. OPERATIVE TREATMENT

The idea of operative treatment is to prevent compression of the lunate; to improve the blood supply of the lunate directly or indirectly; to improve the stability of the wrist; or to remove the diseased lunate and possibly replace it with various materials. The measures are aimed at preventing wrist collapse and arthrosis resulting from compression of the lunate. Late-stage treatment of the disease involves proximal row carpectomy (PRC) or wrist fusion, arthrodesis, and wrist arthroplasty. The degree of Kienböck disease affects the choice of treatment.

2.11.1. Biomechanical factors in the design of surgical interventions

Biomechanical studies have been useful in investigating the pressure on and load of the various wrist regions and the peak pressure by loading the wrist directly either axially or via tendon units. Studies have involved cadaveric wrists, with results recorded with on pressure-sensitive film (Fuji Photo Film Co., Tokio, Japan), a strain-gauge technique, a pressure-sensitive sensor (Yokohama Rubber Co., Yokohama, Japan) or mathematically (rigid body spring model; RBSM) (Horii et al. 1990, An 1993). These techniques have served to determine the effect of surgical procedures on wrist mechanics, with results depending on the method used.

In the normal wrist, of the radiocarpal pressure, 78% is distributed in the radius and 22% in the ulna. In the radius, 46% of the pressure is divided into the radius fossa and 32% into the lunate fossa. For the ulna, respectively, 14% into the ulnolunate part and 8% the ulnotriquetrum part. In the midcarpal joint, 31% of pressure is on the STT joint, 19% the scaphocapite, 29% the lunocapitate, and 21%

the triquetrohamate joint (Horii et al. 1990). Examined with a pressure-sensitive film, the axial load of the carpus for the radius was 88%, and for the ulna 22%, corresponding well with the previous ones (Werner and Palmer 1993, Coe and Trumble 1993).

The general perception is that the minus variance of the ulna increases lunate compression because the bone consistency is harder than is the triangular cartilage thickened in the minus variance. This has resulted in surgery that equalizes the levels. Radius shortening osteotomies and ulnar lengthening procedures are considered in the minus variance. In the ulna plus variance has also been used shortening of the capitate procedures. In the study of Horii et al. (1990), ulnar lengthening or radial shortening by 4 mm reduced the radiolunar pressure by 45%, and peak pressure decreased by 37%, while ulnolunar pressure increased by 50% and ulnotriquetral by 78%.Capitolunar pressure decreased by 13% and radioscaphoid pressure increased by 6% (Figure 7).

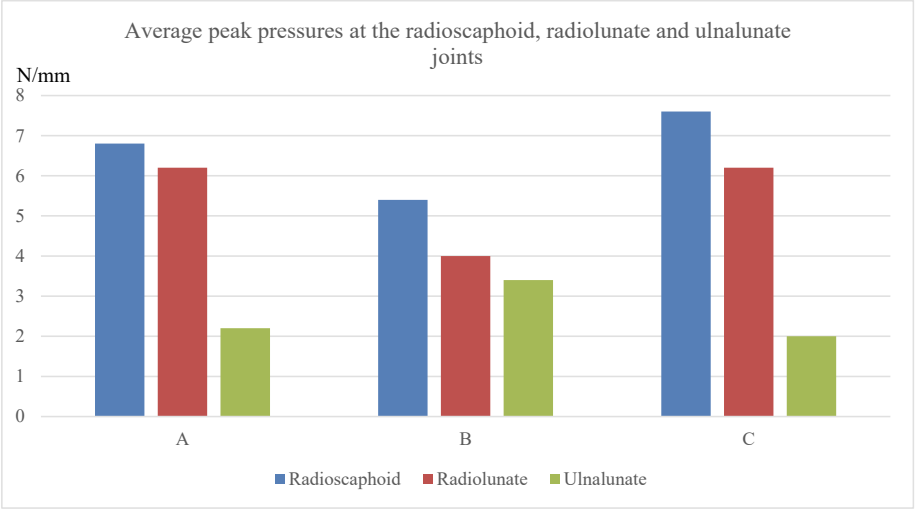

Figure 7. Average peak pressures at the radioscaphoid, radiolunate and ulnalunate joints in intact wrist and after simulated three operations
A. Intact wrist, B. After simulated radial shortening/ulnar lengthening of 4 mm, C. After STT fusion. (Modified from Horii E et al., 1990).

Werner and Palmer (1993) had a similar result with a 2.5 mm lengthening: radiolunar pressure dropped to half, ulnolunar increased to more than double, and radial shortening did the same. Peak pressure (N/mm²) of the ulnolunar joint increased from 1.4 to 3.4 and radioulnar pressure decreased from 3.0 to 1.5. Radioscaphoid pressure increased slightly from 3.3 to 3.4. In radius wedge

osteotomies, both the lateral opening osteotomy and medial closing osteotomy caused increased pressure on the ulna, lateral opening 0°-15° from 20% to 51% and medial closing osteotomy from 15% to 51%. Lateral closing osteotomy reduced the pressure on the ulna from 31% to 8%. Of these two procedures (lateral opening and medial closing) even 4° and 8° change reduced the pressure on the lunate fossa of the radius, but radial closing osteotomy increased it. Radial closing wedge osteotomy led to increased pressure of the radiolunar fossa and lateral opening osteotomy, and medial closing osteotomy decreased (An 1993). Of the pressure drop, 90% occurred during the first 2-mm radial shortening or ulnar lengthening (An 1993). Makabe et al. (2011) found that after the radial shortening osteotomy, the subchondral density of the bone decreases in the radiolunate fossa, then the pressure on the lunate also decreases. Shortening the radius and lengthening the ulna can thus reduce the compression on the lunate in the radiolunate fossa. These measures leave the wrist joint untouched and do not prevent the wrist from collapse.

The capitate shortening osteotomy also reduces compression on the lunate. A 1.8- to 2-mm shortening reduces axial load by 49% to 56% (Werber et al. 2012). Horii et al. (1990) found that the pressure on the radiolunar joint decreased by 66%, the radioscaphoid joint pressure increased by 26%, and the scaphotrapetzial joint by 69%, and the ulnotriquetrial joint by 114%. Between the type II lunate (hamate facet) and the hamate may emerge an impingement situation. There is also a proposal for simultaneous capitohamate fusion (Almquist 1993).

The aim of intercarpal arthrodesis is not only to reduce compression to the lunate but also to stabilize the wrist. The tendency is to stabilize the wrist and thus prevent the wrist collapse associated with lunate compression and scaphoid twisting in flexion. This condition is considered to be conductive to arthrosis.

Short et al. (1992) measured the effect of position of the scaphoid on the radiolunar joint load with their simulated cadaver model. Pressure-sensitive film (Fuji super-flow and low-pressure film. International Business Promotion, Fort Lee, N.J.) was used in the measurement. Pressure in the scaphoid fossa was 50% when the lunate was intact, 75% with the scaphoid fixed to neutral position, 82% in extension position, and 38% in flexion position and in a state of collapse the pressure was 52/80/84/44. Correspondingly, in the lunate fossa, the pressure was 29/16/15/49 and in collapse 31/14/15/48. In the TFCC fossa, the corresponding readings were 21/10/4/13 and 18/7/3/9. Their conclusion was that the scaphoid fusion in neutral or extended position reduced the load on the radiolunar joint irrespective of the lunate situation. Iwasaki et al. (1998) found that scaphocapitate fusion and STT fusion significantly reduced the joint force of the radiolunar and lunocapitate joints and significantly led to increased pressure on the radioscaphoid joint. Capitohamate fusion affected neither. The STT fusion also added pressure to the scaphocapitate joint and the scaphocapitate fusion to the STT joint and the

triquetrohamate joint. A change in pressure distribution may affect degenerative changes in these joints.

Werner and Palmer (1993) tested STT arthrodesis with both an intact lunate and simulated collapse. The pressure on the lunate in a neutral position of the scaphoid was the same as without compression: it decreased from 29% to 15% in extension and increased in flexion to 49%. When the lunate was compressed, the basic pressure was 31%, in neutral position 14%, in extension 12%, and 48% in the scaphoid flexion position. The STT arthrodesis reduced the pressure on the lunate fossa. With the capitohamate fusion, no similar effect emerged.

Coe and Trumble (1993) concluded in their review article that STT arthrodesis reduced lunate compression by 70% compared with the "relative ineffective" capitohamate fusion. In ulnar deviation over 10 degrees, the effect of STT arthrodesis was considerably lower. The effect of scaphocapitate arthrodesis on the load was similar to that of the STT arthrodesis. Both arthrodeses restricted the extension- flexion movement, STT 16% and SC 13%. Radioulnar deviation decreased by 20% in STT arthrodesis and 26% in SC arthrodesis.

Horii et al. (1990) stated that STT arthrodesis reduced the load on the radiolunar joint by 5% and peak pressure by 3% and increased the same changes in the radioscaphoid joint by 4% and by 11%. In the scaphocapitate arthrodesis, the change in the radiolunar joint was 12%, and was 11% in the lunocapitite joint. Peak pressure increased by 17% in the radioscaphoid joint, decreased by 8% in the radiolunar joint, and by 10% in the ulnolunar joint. In the capitohamate fusion, there occurred no change in the radiocarpal plane, but the pressure at the lunocapitate and scaphocapitate joints increased by 18%. Combined with the capito-hamate arthrodesis, after capitate shortening osteotomy, the pressure in the radiolunar and scaphocapitate joints decreased significantly, 66% and 52%, respectively. Viola et al. (1988) found a similar procedure to raise the pressure of the radioscaphoid joint and reduces the radiolunar pressure but the effect on the radiocarpal pressure was low.

2.11.2. Lunate excision

Lunate removal has previously been used in situations where conservative treatment, mainly immobilization, has not produced results, and the patient was still in pain.

Lunate removal leads to wrist instability and collapse. Ståhl (1947) stated in his follow-up study that the removal of the lunate leads to a poor outcome. In the follow-up examination of 10 patients, 9 to 19 years later, mobility was significantly reduced, functional force was about 50%, and the wrists had undergone ulnovolar subluxation. X-ray images showed strong structural changes in the lunate and

moderate arthrosis in radiocarpal and midcarpal joints. Two results were good, four moderate, and three poor. One of the patients was unable to work and had changed profession.

Finnish publications are from Pentti Honkanen's 1937 article in *Duodecim*, "Kienböckin taudista ja sen suhteesta tapaturmaan" (Honkanen 1937). Nine patients were described, especially with regard to their possible trauma etiology. The author refers to problems after removal of the lunate and did not recommend it as a treatment.

Dornan (1949) compared 27 non-operatively treated patients to 16 patients who had had a lunate excision. The patients had been treated during the previous 10 years. Those surgically treated were young patients who had no wrist degeneration. The groups were not directly comparable. 63% of those conservatively managed and 69% of those with surgery returned to work. One of the operated-on patients had wrist fusion later.

In the 13-patient study of Einola et al. (1979), the indication of lunate removal was pain and severe deformation and fragmentation of the lunate. One patient had also a capsuloplasty am. Nahigian. The follow-up period was on average 2.6 (0.5-7.9) years. Five of the patients were painfree, five had pain during hard exertion and one during mild. One had a wrist fusion 6 months after lunate removal due to pain. Two patients were retired, and others continued working. Grip strength was on average 47% of the strength of the healthy side. Ten patients had a limitation of flexion movement, and seven had a limitation of deviation movement. Two wrists had collapsed, arthrosis existed already primarily in six wrists. The authors stated that removal of severely deformed and fragmented lunate prior to the development of arthrosis changes yields a very good primary outcome both in relief of pain and in ability to work.

Kawai et al. (1988) published on 14 patients after lunate removal. The average follow-up time was 11.6 (5.6-18.8) years. Preoperatively, eight patients had severe pain and six moderate pain. At follow-up, two had moderate and five mild pain, seven were painfree. Daily activities were successful, only one patient had to change his work for lighter work. Grip strength improved from 40.6% to 77.5% compared to that of the healthy hand. The average extension was 41.8°, flexion 40.4°, radial deviation 12.2°, and ulnar deviation 21.3°. The carpal height ratio was preoperatively 0.54 and at follow-up 0.52, and the carpal ulnar distance ratio respectively 0.30 and 0.32. Collapse of the wrist occurred, the capitate migrated proximally, and the triquetrum and scaphoid twisted to palmar flexion. Degenerative changes were less than expected.

Lunate removal is now excluded due to the "disintegration" of the wrist and unavoidable collapse.

2.11.3. Lunate removal and interposition-arthroplasty with biomaterials

Carroll (1997) presented in 1997 the use of fascia to replace the lost lunate, and his findings were published with an average of 17.9 (10-34) years of follow-up. He used, as interposition, fascia lata, palmaris longus tendon, plantaris tendon, long toe extensors or flexor carpi radialis tendon. Patients numbered 10, and their initial status has not been described. Everyone had returned to their former job, and no significant pain occurred. The ROM was incomplete, flexion 17° and extension 27°. In radiographs, the interpositions all had calcified deposits, and there was no collapse of the wrists, although the height of the wrist was lowered. In one patient, arthrosis had progressed. The author considered it important that the lunate state was filled with a tight graft and the wrist was immobilized for 6 weeks.

Kato et al. (1986) published data comprising 13 palmaris tendon arthroplasty and 19 silicone arthroplasties. The average monitoring time was 6.3 (3-11) years. Results were evaluated especially in relation to pre-operative wrist collapse. While the collapse was mild, both methods were reasonably good, and neither of the methods yielded a favorable result in the more advanced collapses.

Ueba et al. (1999) used the combined palmar and plantar tendon interposition and postoperatively the wrist distraction made by the external fixation for four weeks (Table 3). The number of patients was 22 and the disease was stage II in one, stage III in 10, and stage IV in 4. The follow-up period of 15 patients was 16.2 (9.7-23.3) years. Six patients were unavailable for follow-up, and one was excluded due to surgical infection. The patients were painfree, ROM slightly increased (14°), and the grip strength was 90.2% of a healthy side. The carpal height ratio was preoperatively 0.53 and at follow-up 0.49. The result was rated excellent on nine and good on six. The authors attach importance to the adequate size of the implantable tendon ball, the retention of the wrist volar capsule in surgery as intact, and the use of the distraction in postoperative phase.

Yajima et al. (2004) published data on 21 patients, in whom stage IIIB occurred in 12 and stage IV in 9. In 17 patients, the lunate had fragmented. The average monitoring time was 2.6 (1-5.7) years. The palmar longus tendon was used for two and extensor carpi radialis brevis for 19 patients. The palmar tendon was used with a bone transplant around which the tendon was placed. The immobilization took 3-5 weeks, and additionally, the temporary fixation of STT (19) or the scaphocapitate joint, was in place for an average of 9.8 weeks. Nine patients became painfree (43%), others had pain at exertion. The extension-flexion improved by 12°, and the grip strength improved to 64% of the contralateral side. The CHR survived: 0.47 vs. 0.46 at follow-up, and the radioscaphoid angle improved from 61° to 47°. Arthrosis evolved in three patients (14.3%), one of which case was in the scaphocapitate joint potentially due to bioabsorbable fixation. Six fixation wires loosened prematurely.

After removing the wires in 10 cases, the height of the wrist was slightly lowered. The authors estimated that STT fixation could be useful to maintain wrist height.

Matsuhashi et al. (2011) published on 12 patients, where according to Lichtman's classification, 6 had stage IIIA, 5 stage IIIB and one stage IV. As the interposition they used a palmar longus tendon, and the bone transplant was either the removed lunate or bone taken from the crista. The monitoring period was 3.4 (2.7-7) years. Four patients (30%) were painfree, extension flexion improved significantly (28°) and grip strength from 46.2% to 83.7%. All had an excellent Nakamura scoring result. One patient had arthrosis, and one transplant was dislocated. The bone transplant was lost or decreased in half the patients. There was no difference in the carpal height ratio of the wrist compared to preoperatively. The authors note that the procedure had a therapeutic effect in advanced Kienböck`s disease.

Sakai et al. (2004) compared an interposition with a palmaris tendon to another patient's, who also had a bone transplant from the removed lunate, 7- to 8-mm in size, and in addition, a tendon was transplanted. The wrist was immobilized for 3 weeks. This series comprised 16 patients and 17 wrists, with classification stage IIIA or IIIB. In seven cases, only the palmaris tendon was used for a follow-up period of 46.4 months and in ten cases also a bone transplant, with an average follow-up of 13.3 months. All patients returned to their former work. One patient suffered the complication of CRPS I type of pain. No difference appeared between the results in the clinical evaluation. In this series, as well, bone transplants were lost in 20% and in 40% decreased to less than half their size. However, CHR was significantly higher in the bone-transplant group.

Zeplin and Ziegler (2013) published on 10 patients, in whom lunatomalacia was stage III to IV (Table 3). The interposition was the palmaris longus tendon, and the follow-up time was on average 18.5 (15-22) years. Five other patients dropped out of 15, three of whom were later subjected to a a different measure. DASH score averaged 12 and the Cooney-Bussey score (MWS) 75. Seven patients remained in their former job, two were retrained, and one was unable to work. Extension was 65% and flexion 70% of the contralateral and grip strength 75%. All patients had arthrosis of the radiocarpal joint, 80% had STT and hamatotriquetrial arthrosis, and 70% radioulnar arthrosis; 90% of these patients had carpal collapse. The authors thus did not recommend that procedure for treatment of stage III to IV lunatomalacia.

Mariconda et al. (2013) published data on 26 patients, using a palmaris longus transplant (Table 3). Two of the patients had Lichtman stage IIIA, 23 had stage IIIB, and one stage IV. The average follow-up time was 10.4 (4.2-18.8) years. DASH score was 7.7 (SD 8.6; range, 1-26), and pain on the VAS scale 1 (SD 1.4; range, 0-5). Fourteen patients were painfree. Extension improved significantly. Flexion was 56%, extension 58%, and grip strength 84% (33 vs 40 lbs) of the value of the

contralateral. In MRI, more than half the patients were diagnosed with cartilage defects, erosive alteration of bone and bone edema, synovitis, and TFC damage. But these changes were mostly mild. The mean CHR was 0.49 before surgery and 0.45 at the follow-up. In the MRI and CT studies, calcification or ossification was evident in all palmaris longus transplants. The change in the radioscaphoid joint was the only one that correlated with the DASH value. Arthroplasty did not prevent the wrist from collapsing. Despite radiological changes, the clinical outcome was good. The result corresponds to the meta-analysis of Innes-Strauch (2010) that tendon ball arthroplasty produces the highest percentage of painfree patients in the late stage of lunatomalacia, despite the loss of carpal height.

In summary of these findings, it may be noted that the tendon interposition does not prevent the wrist from collapse, and it is mainly indicated for advanced changes as in Stage IIIB to IV. Moreover, the results of the tendon transplantation do not appear directly to correlate with radiological status. The complications associated with this surgery are minor, but interposing arthroplasties have not become widely used (Kolovich et al. 2016).

Huard et al. (2011) published data from four patients in which the lunate was replaced by a costochondral graft taken from the ribs in Stage IV. The follow-up time was short 2.2 (0.5-3) months. The functional result was good, rest pain disappeared, DASH was 6, flexion-extension 108°, and the grip strength 83% of the value of the healthy side.

Table 3. Long-term results (mean ≥ 10 years follow-up) of different treatment modalities in Kienböck's disease. Lunate tendon arthroplasties

Authors	Year	N patients/ wrists	Treatment	Initial Lichtman stage I / II / III / IIIA / IIIB / IV	Follow-up time, years mean (min-max)	Pain VAS or presented numbers	Grip strength % of contralat.	ROM[1] ext/flex (°) or % of contralat.	DASH[2] mean (min-max)	MWS[3] mean (min-max)	Progression (in Lichtman stage), %.	Arthrosis presence %
Ueba et al.	1999	15	PL+ EDL IV	0 / 1 / 10 / - / - / 4	16 (9-23)	no pain 15	90	48°/37°	-	-	-	-
Zeplin and Ziegler	2013	10	PL	III-IV	18 (15-22)	VAS 2.6	75	38°/42° 65%/70%	12	75	-	100
Mariconda et al.	2013	26	PL	0 / 0 / - / 2 / 23 / 1	10 (4-19)	VAS 1 (0-5) no pain 54%	84	48°/40° 58%/56%	7.7 (1-26)	-	-	MRI: bone erosion 80%

[1] Range of motion; [2]Disabilities of the Arm, Shoulder and Hand; [3]Mayo Wrist Score.
Abbreviations: PL = palmaris longus, EDL = extensor digitorum longus

2.11.4. Implant arthroplasties

In lunate implant arthroplasty, a damaged lunate is replaced by an implant whose shape is as good as possible, compared with normal. Implants have been used since the 1940s. The material has fluctuated: for example, vitallium, titanium, acrylic, silicone and pyrocarbon. The problem with an implant is the instability caused by surgery, the main reason for which is the loss of support from the intercarpal ligaments. In addition, the size of the implant may not correspond to the space generated by the lunate resection. The implant material has not the same consistency as the bone and the implant material can also cause problems. Instability may also be related to subluxation or total dislocation of the implant. The most widely used was a silicone implant launched by Alfred B. Swanson in 1970.

Lippman and McDermott (1949) published a case report from a single patient with lunate arthroplasty using a vitallium replica after unsatisfactory conservative treatment. The primary recovery was good and uncomplicated.

Agerholm and Goodfellow (1963) published 15 patients treated with an acrylic prosthesis. After an average 4.8 years the result was good, 8 patients were painless, and 4 patients had mild pain on exertion.

2.11.4.1. Silicone implant

The silicone implant results were published as early as the 1970's: Michon (1973) published on a series of some patients mainly demonstrating the primary outcome. Roca et al. (1976) published data on 10 patients. They, like Michon, emphasized the importance of volar surgical approach to avoid the dorsal dislocation of the implant. The monitoring period ranged from 24 to 30 months. Three of the results were bad, and two of those implants were palmar subluxated. Seven patients received a good result: six were painfree, and one had mild pain.

Ney (1977) published on both scaphoid and lunate implants, and in some cases both bones were replaced. He had nine lunate implants; two luxated and one subluxated. In four patients, the pain disappeared, and in five it decreased, strength and motility improved in 78% of these patients. The subjective result was excellent or good in 89% of the patients. The monitoring time is not reflected in this study.

Lichtman et al. (1977) sought to investigate in 38 patients whether prolonged immobilization prevents progression of lunate changes and whether silicone arthroplasty is a better option than immobilization. In addition, the aim was to discover at which stage the arthroplasty should be performed and when other measures should be taken. In the article they also described the surgical technique used later, emphasizing the preservation of the wrist volar capsule intact, and the correct size of the implant and the reliable dorsal joint capsule closure. The result was considered satisfactory if the grip strength was 75% of the contralateral, the ROM was not more than 10 ° lower than the initial value, the patient was

able to work and take part in activities, and the pain was intermittent and mild. Here, 22 patients had been treated for 2 to 14 months of immobilization and in 17 patients of those, lunate collapse progressed. In 19 patients the result was unsatisfactory; 20 underwent silicone arthroplasty. The changes were graded with Lichtman's classification which he presented in this article. In stage II, the result was satisfactory in eight of nine patients. In stage III, four of ten patients had dorsal or volar subluxation of the prosthesis, and the result was unsatisfactory. One patient in stage IV had later wrist arthrodesis. Early diagnosis was significant in addition to surgical techniques, and implant-arthroplasty was recommended at an early stage, but not in Stage I. Stage IV was unsuitable for arthroplasty, and conservative treatment yielded a poor outcome. The mean follow-up time was 2.2 (0.8-4.5) years for the implant arthroplasty.

Stark et al. (1981) published data on 36 patients receiving a silicone implant. Of these, 29 were 16 to 40 years old and had a trauma history. Everyone had stage III disease, and the implant was not used if the shape of the lunate had survived. In 33 patients, CHR was less than 0.51, and CUDR was in 25 <0.27, and in 9 (26%) of these had both meaning carpal collapse and translation. (Youm et al. 1978). The implant was molded to fit, because due to deformation, the volar space was narrower than the dorsal. Too large an implant was avoided to prevent dislocation risk. The monitoring period was on average 4.1 (1.3-11.9) years. In three patients, the result was poor, and two of these were arthrodesis. The researchers concluded that the implant is indicated only when the lunate is deformed, and the wrist has already collapsed.

Bertini et al. (1982) studied 18 patients who underwent silicone-arthroplasty and were followed up for 0.5 to 7 years. The stage was II in nine patients, stage III in eight, and IV in three, one was a reoperation. One implant subluxated, and one dislocated, resulting in reoperation. Of all results, 94.5% were estimated to be good, and only one was poor. Pain was normalized in 4 and decreased in 14 patients, and 15 were able to perform their jobs. Their wrist movement improved. Arthrosis existed in those followed more than 5 years. No complications emerged as being due to the implant material, and the result was considered quite good.

Ramakrishna et al. (1982) treated eight stage III lunatomalacia patients each with an implant. Conservative treatment proceeded in all cases for an average of 45 months, with the follow-up time being on average 7 years. One implant was dislocated postoperatively and the other one 6 years after the initiating fall. With all the pain relieved, motion extension / flexion was for both a mean 40 degrees. Work return was successful for everyone. There were radiological changes: three had cystic formation in the scaphoid, and four had initial degeneration in the radiocarpal joint, one in the radioulnar joint, and seven patients had sharpening of the edge of the radius. Four implants were volarly subluxated. The authors

compared the results with the outcome of the lunate removal and stated that they were not unambiguously able to keep the implant more functional. They considered that lengthy preoperative conservative treatment could have a negative impact on the outcome and thus suggest limiting conservative treatment to 6 months.

Eiken and Necking (1984) published on an implant study with 19 patients, most of them were the 17 patients with stage III, one with stage II and one with stage IV. The mean follow-up time was 12 months (6 months to 5 years). Seven patients were implanted from the dorsal approach (group A) and the other six patients from the same approach, but with the stem for fixation removed and the implant temporarily fixed by K-wires (group B). For six patients, the implant was inserted through a volar approach, and in this group the stem was also removed (group C). After-care was a splint for 4 to 6 weeks. In group A, two patients became painfree, and two had a wrist fusion. There was a cavity around the implant's stem in two cases, and two stems fractured. They were subjected to bone transplantation and new implantation. Two implants were in dorsiflexion and two in volar subluxation. The scapholunar gap had spread in four cases. Intercarpal degeneration was observable, and the capitate showed cyst formation in two cases. In group B, for five of the six, pain was relieved. One experienced a wrist fusion. Again, progressive intercarpal degeneration was observable in this group, one implant was volary subluxated, and in four cases the scapholunar gap spread. In group C, all patients were satisfied; they had no activity limitations. Radiologically, the scapholunar gap was normal, with no implant subluxations present. The authors considered that the volar approach secures wrist stability and creates the preconditions for avoiding implant-related problems.

Swanson et al. (1985) published a review article involving 42 patient records for those who had been followed for at least one year. In stage II to III, they used the implant, and in the progression of the disease (stage IV/V), it was preferred to stabilize the wrist by intercarpal arthrodesis, especially for heavy-duty workers. Negative ulnar variance (67%) did not correlate with the result. Stage II- to III patients were painfree. Cystic changes and degeneration were mild in 11 wrists and moderate in 3 (33%). Four patients underwent further surgery, two of them at 4 and 8 weeks after the dorsal subluxation of the implant. One scaphocapitate fusion was done because of cystic changes and in addition bone transfer and implant replacement, and another patient had, due to ulnar translation, synovectomy and ligament tightening. In wrists with cystic change, instability or a collapse was found.

Viljakka et al. (1985) published 53 patients with an average 2.5 years follow-up. 18 wrists were painless and pain on exertion diminished in 91% of patients. 26 patients continued in their former work and 22 changed to lighter one. Mild arthrosis was noted preoperatively in 22 and at follow-up in 42 patients and cystic bone changes had emerged in six patients.

Backaert et al. (1985), published 19 patients with on average 6 (2-10) years of follow-up. In four patients, the implant was dislocated; two of these were re-implanted. The motion was 64% contralateral and the power grip strength 72%. The mean follow-up period was 6 (2-10) years.

Kato et al. (1986) compared the results of a tendon interposition and along with the silicone implant. At an early stage of lunatomalacia, the implant was retained better the wrist height, but at late stages, the implant result was unsatisfactory due to the progression of arthrosis and the subluxation of the implant. Implants were set for 19 patients and a tendon interposition for 13 patients with mean follow-up of 6.3 (3-11) years. Synovitis caused by implants was detected in two patients.

In our own material (Viljakka et al.1987), monitoring time was a mean 3 (0.5-11) years. The stage of disease was I / one patient, II / 6, III / 38 and IV / 7, with no preoperative picture in three patients. As complication was one infection of the implant, five implants were dislocated, and three were removed. 12 implants were slightly subluxated. Pain at rest was relieved for 53, but not on strain in 50 patients. The motion remained on average about one-third less than on the healthy side, and the grip strength was 69% of the average contralateral. A total of 42 patients (76%) had mild arthrosis changes in the radiocarpal or intercarpal joints. In 11 cases, most commonly in the capitate and hamate, cystic changes occurred. The cystic change included silicone in an electron-microscopic study (Telaranta et al. 1983). Those returning to their former job numbered 28, and 22 had lighter jobs.

Özsoy et al. (1988) had 21 patients with a monitoring time averaging 23 (6-46) months. Two-thirds of these patients were painfree. One patient had a carpal tunnel opening, and two implants were dislocated.

Kern and Rodrigues (1988) reported data on seven patients. All patients were satisfied, follow-up time was nearly 3 years. Wrist movement improved (extension 31 ° and flexion 18°). Radiologically, four implants had tendency to protrude at the proximal pole after four years and two patients had cysts in carpal bones. The authors considered silicone implant arthroplasty suitable for stage III malacia.

Alexander et al. (1990) followed 10 implant patients for a mean 5 years. Three of the longer-monitored five patients developed particle-wear silicone synovitis. Two results were poor, the third patient had cysts in the scaphoid, capitate, triquetrum, and radius, although he was symptom-free. The article refers to a research result in which silicone and other polymers (polymethylmethacrylate and polyethene) cause in the synovia a similar histological and histochemical change as in rheumatoid arthritis, i.e. increased prostaglandin E2 and collagenase production. The difficulty of the reaction is inversely proportional to the size of the particles and correlates with the particle production and the duration of the exposure, not to the chemical properties of the polymers. Researchers note that the silicone implant is suitable only for stage-III late phase, so it is necessary to

stabilize the scaphoid by scaphocapitate or STT arthrodesis. The use of implants should be treated with caution and contemplation of other treatment options.

Ham et al. (1990) reported on an 18-patient series with a follow-up time of 12.2 (8.4-15) years. In four, the implant had previously been dislocated and required reoperation. In most patients, the pain had decreased, and wrist function was acceptable. The extension-flexion was 69.7% and the grip strength was 70% of the contralateral. Eight patients experienced a significant effect on their working, and one was unable to work. Intercarpal and radiocarpal degeneration had increased.

Swanson and de Groot Swanson (1993) published their experience on their lunate implants. The first nine patients in 1968-1973 were treated with a 372-elastomer silicone implant. Of these, one had a revision procedure done for a dislocation. An HP silicone implant was implanted into 51 patients between 1974 and 1985. One was revised due to progressive cystic changes and one for progressive ulnar translation. The authors mention that they had used, starting in 1985, a titanium implant for 24 years, and one of them had a wrist partial fusion due to the scapholunate instability problem. The authors emphasize patient choice, if-necessary wrist-stabilizing partial fusion, the operative technique, and avoiding too large an implant. In summary, they considered implant arthroplasty still useful as a procedure.

In our own study (Viljakka et al.1995), we followed 43 silicone-implant patients for an average of 11.8 (9-19.9) years. Wearing and deformation of the implant were noted in 88%. Only one patient was completely painfree, and in 25% of the patients, pain was classified as difficult: 24 patients had difficulties in their work, 10 had moved to lighter work and three retired. Mild or moderate arthrosis changes were evident in 91% of patients and cystic changes in the wrist area in 65% of patients. At three years follow-up, cysts appeared in 20% of patients (Viljakka et al. 1987). The conclusion was that silicone arthroplasty should not be recommended for use.

Kaarela et al. (1998) published on 39 patients with an average of 8 (1-18) years of follow-up. During the follow-up, 16 implants were removed, 15 of these due to pain, to silicone synovitis, and to associated cyst formation in the wrist bones. Of these patients, 22 had stage II illness, 16 stage III and one stage IV. After three years of follow-up, the situation was good, 26 of 39 patients had no problems, although five implants had been removed. At five years, only half the results were satisfactory, and eight implants required removal. In total, silicone synovitis and cystic bone changes developed in 34 of 39 wrists. Changes occurred between 0.5 and 10 years (average 4.3 years). There was no correlation with the change in the radioscaphoid angle, nor with the ulnar variance nor the workload. Six patients were subjected to simultaneous RSO, which did not prevent the formation of cysts. As a conclusion, they considered that lunate silicone implant use should be discontinued.

2.11.4.2. Silicone synovitis

The first references to silicone-induced synovitis came back in the 1970's (Aptekar et al. 1974) and subsequently (Telaranta et al. 1983, Ekfors et al. 1984, Eiken et al. 1985). Smith et al. (1985) reported nine patient's development of silicone synovitis following a wrist implant. Of these, four were lunate implants for which the deformation was the most intense. On the surface of the implant developed electron-microscopy-visible fibrillation and flaky silicone particles 6 to 100 microns in size leading to villous edematous hypertrophy of the synovia. That generated a chronic inflammation with lymphocytes and plasma cells as well as fibroblast cells surrounding the silicone-debris regions. This was related to bone cortical erosion and cystic bone defects. Silicone particles spread via vascular and lymphatic routes into the surrounding tissues. The development of synovitis did not require implant misalignment, but constant compression and attrition leading to a change in the implant and thus to the wrist's collapse. As one explanatory factor, the authors mention "high performance silicone," These authors considered it important to follow the patients for at least eight years and when the synovitis appears, to remove the implant, to perform synovectomies and, as appropriate, assess other measures.

There were included in this data of the Smith group also two scaphoid implants, one trapezium. and one trapezium-resurfacing implant, as well as one wrist implant. According to them, MP implants have less synovitis because of less compression on these joints (Smith et al. 1985).

Minami et al. (2005) published a follow-up study of 12 thumbs with MP-joint silicone implants with a follow-up of an average 15 years. In four cases, bone erosion occurring around the implant was interpreted as synovial.

Eiken et al. (1985) reported on 48 patients with an average of 2.4 (0.5-6.8) years of follow-up. In Kienböck's disease, the implant had been used for 21 of these patients. Reactive synovitis and disseminated cyst formation had occurred in 11 patients, the first cystic formation already at 8 months. The histological findings of the synovia were similar to those reported by Smith et al. in 1985. With wrist implants, cystic changes occurred already during the 33-month follow-up period. The mechanisms for etiology of bone changes are not entirely clear, possibly the destruction is the result of macrophage-produced proteolytic enzymes. Researchers warn about the use of silicone implants in proximal wrist arthroplasty, especially in young people, as the long-term biological effects are unknown.

Carter et al. (1986) published their data on 53 wrist implants including 11 lunate implants. Lunate implants were associated with lytic changes in the bone in 55% of cases. The average follow-up time was 4 (2-7) years. Ten of the 53 implants had to remove, and the result was often unsatisfactory. The conclusion was that silicone implants for younger healthy patients are seldom indicated, and implants should be closely monitored.

Lanzetta et al. (1994) presented 229 wrist implants with a follow-up period of 3.8 (1-15) years. Only seven lunate implants were performed—one of them underwent implant removal due to synovitis and the result was good. Overall, 40% exhibited radiological changes but only 11 patients (4.8%) developed symptoms requiring treatment. The authors note that reoperation is not indicated due to radiological findings alone and consider that the silicone implant was still a useful treatment.

Silicone implant treatment offered a technically rather easy choice of treatment that seemed to be quite promising—the primary results being good. Primary results were almost exclusively compromised by implant dislocation, and these averaged in presented materials 8.1% (0-25) of patients involved. In longer follow-up, degenerative changes and collapse (scaphoid twisting on flexion and proximal translocation of the capitate) increased, and the wrists began to increasingly develop changes due to silicone synovitis. There seems to be a fairly large variation in the appearance of synovitis and bone changes, however, with the overall picture being increasing changes. As a result of complications, lunate silicone arthroplasty has now been abandoned.

2.11.4.3. Titanium implant

Because of the material problems of the silicone implant, similar implants have been developed from other materials. Swanson et al. (1997) published a lunate titanium implant (Wright Medical Technology, Arlington, TN) follow-up study. The implant is similar in shape and implantation technique to a silicone implant and has five trial implants. The only difference is the implant's fixation with intraosseal stitches to the scaphoid and triquetrum, stitches passing through the channels in the implant. In addition, if the wrist is unstable when testing, Swanson recommends STT or scaphocapitate arthrodesis, and possible bone cysts should be treated with a bone graft.

After 1985, an implant was used for 35 patients, and 21 of them attended the follow-up at 1 to 9 years. The indication was stage III- to V lunatomalacia. According to Swanson's classification in I to VI, in stage V, the lunate is cystic, sclerotic, and fragmented, and the radioscaphoid angle is over 70 degrees, CHR collapse more than 10%, and the wrist has cystic changes and significant ulnar translation. One patient had radiocarpal osteoarthritis, and four had a silicone implant revision with a titanium implant. One of the implants subluxated and was re-operated, and one radiocarpal fusion was necessary. Of 21 patients, 19 had "excellent pain relief." Six were completely painfree, 13 had pain during strain, and 2 had persistent pain—one of whom had arthrosis necessitating wrist fusion. Of these 19, all had returned to their former jobs. Extension-flexion averaged 38° / 32°, radial deviation 17° and ulnar deviation 20°. Their grip strength improved from 44 pounds to 69 pounds (60-130 pounds). No significant difference existed between the carpal indices and

its preoperative value. The radioscaphoid angle was 56°, CHR 0.47, and CUDR 0.27. The authors considered these results excellent in terms of pain, and the balance of the functional movement and stability as good, as was also the restoration of grip strength. The bone and soft tissue response were excellent, as well.

2.11.4.4. Pyrocarbon implant

Henry (2014) published results for 13 patients with lunate fragmentation and cartilage delamination indicating advanced Kienböck's disease and meaning an unsalvageable lunate. He categorized Kienböck's disease into three degrees: early disease (MRI changes, no collapse), progressive (collapse in X-ray images, CT salvageable), and unsalvageable (fragmentation or delamination in CT). The author used a pyrocarbon implant stabilized by a flexor carpi radial-tendon sling. This was transplanted through the implant to replace the SL and LT ligaments. The wrist was immobilized for 8 weeks and further supported from the radius to the scaphoid and the capitate with Kirschner wires for 4 to 6 weeks. The follow-up period averaged 30 (14-43) months. Motion, grip strength, and DASH score improved statistically significantly from baseline. DASH score was 7.7. Extension/flexion was 43° / 53°, grip strength 31.5 kp (85.2% of contralateral). The SLA was 46.7° and the RSA 42.1°. One patient was subjected to PRC due to instability, one K-wire came loose and was re-attached, and one patient had osteonecrosis of the scaphoid proximal pool and was subjected to PRC. Despite good clinical and radiological changes, the author was not satisfied, because the implant failed to achieve sufficient stability. The plan was to reconstruct the function of the intercarpal ligaments with a new method.

Werthel et al. (2014) published the preliminary results of two patients with pyrocarbon implants after 3 years of follow-up. Kienböck's disease stage was IIIA or IIIB. The result was good, on average VAS was 1 and DASH 11.5. There occurred no change in wrist movement or radiological progression, and grip strength was 76.5% of contralateral.

Visser et al. (2017) published on a series of 16 patients with a pyrocarbon implant and a follow-up time of at least one year. All patients had stage IIIB, and five of them did heavy manual work. The surgery was performed from the dorsal approach, and the implant was supported by an FCR sling which was passed through the scaphoid and further through a hole in the implant and through the triquetrum dorsally when the fixation occurred with the graft itself. One dislocation occurred and was managed with closed reposition and immobilization successfully. One patient was subjected to PRC, with no implications for the implant. Pain relieved, VAS preoperatively averaged 5.6 and at follow-up 2.6, DASH was respectively 31 and 11. PRWE was preoperatively 58 and at follow-up 24. Flexion-extension deteriorated from 98 ° to 72° and grip strength improved 5 kg and to 78% of healthy hand

strength. Radiologically, no worsening of wrist collapse or degeneration appeared during a short-term follow-up. The position of all implants was good. The authors compared their results to the results of PRC and partial arthrodesis, stating that the implant might work for young people instead of salvage, or at least delay it without hampering any subsequent procedures.

No long-term results for these new implants are yet available. The assumption is that the materials used do not have problems such as those with silicone. The stability change associated with lunate removal remains unsolved.

2.11.5. Osteotomy procedures

Radial shortening osteotomy, radius wedge osteotomies, ulnar lengthening osteotomy, simultaneous radius and ulna osteotomy, and capitate osteotomy are all used in the treatment of lunatomalacia.

2.11.5.1. Radial shortening osteotomy, RSO

The radial shortening osteotomy is intended to alter pressure on the lunate in the minus variance of the ulna by moving it from the radiolunar joint to the ulnolunar joint. The ulnar lengthening osteotomy tends toward the same effect. Hultén (1935) described a radial shortening osteotomy with the desired effect. However, osteotomy in the diaphysis region caused a restriction of prosupination.

Axelsson released 19 patient results (1973) with a follow-up time of at least two years. This series included nine minus variants and nine neutral variants, and one plus variant. All patients were painfree, and 17 returned to their former jobs. Lunate structure improved in 37% of the patients. The result was equivalent to the ulnar lengthening study (Axelsson 1973). He also tested various types of osteotomy with cadaveric wrists and ended with a transverse metaphyseal osteotomy.

Eiken and Niechajev (1980) published RSO results in eight patients with follow-up of 3.5 (2-7 years). Seven of these patients were men, all doing heavy work. The disease was always in the dominant hand, with symptoms averaging 3.6 years, and all had an ulna minus variance. Pain relief was 75%, and grip strength improved by 50%. Extension-flexion remained unchanged, deviations improved, and supination deteriorated. Six patients returned to their former jobs. Osteosynthesis was done with Rush pins and cerclage, and no complications occurred. Radiologically, the lunate situation remained unchanged in six patients, with one density decreasing and bone erosion increased. Lunate compression increased in 13%; The Ståhl compression quotient (Ståhl index vs. healthy side) averaged 1.13. Three had mild arthrosis at the time of surgery, and with two of them the arthrosis slightly worsened. The end result was that this measure prevented progressive collapse of

the lunate, the pain relief was less consistent, and denervation could have played a role. The result corresponded with Axelsson's earlier results.

Marti et al. (1981) also used Axelsson's transverse osteotomy that was fixed on a DC- plate, with no immobilization required. The degree of illness did not affect the indication, but in the case of functionally poor wrists, fusion was recommended. Radius resection was 2 to 3 mm depending on the ulnar variance, taking into account the cutting line of about 4 mm. Osteotomy was consolidated within six weeks. Eight patients had RSO, one being bilateral, with an ulnar lengthening osteotomy on one side. Patient mean age was 33 (15-60) years, and the symptoms had lasted usually over two years. For six patients, Ståhl classification was V, for three IV, and for four patients, the lunate was heavily fragmented. After an average of 3 (1-5) years, no complications were evident, but one patient had a traumatic radius fracture on the proximal side of the plate. Four patients had a carpal tunnel release at plate removal and in these patients, the result was very good: they were asymptomatic. The other three were also asymptomatic, but their wrist movement decreased by 10° and the result was rated as good. One patient remained symptomatic, and the result was poor. Radiologically, progression of the disease halted, and in five patients, the lunate structure improved, and no deformation increased significantly. In the four most deformed cases, the lunate remained as interposition inhibiting capitate migration, and the clinical outcome was good. The authors considered the measure to be the primary choice for malacia, taking into account the ulnar variance. Moreover, RSO will not complicate any subsequent measures.

Ovesen (1981) presented seven patients, and one of them had pain on strain after an average 3 years follow-up. Mobility of the wrist improved in four patients.

Almquist and Burns (1982) had operated 12 patients. Ulna minus variance was 2-5 mm and all were followed-up for at least 5 years. No complications encountered. 11 of 12 patients were satisfied, but no one was completely painless in strain. Total ROM improved an average 40° and grip strength was 80% of the healthy side. All but one returned to their normal activities and none of them had progressive collapse or fragmentation of the lunate.

In the seven-patient material of Kinnard et al. (1983), six had complete pain relief at a mean 3-year follow-up, and three of four doing burdensome work returned to their former jobs. Grip strength improved in only three and ROM in two cases. Radiologically, five became better, two had no change. The authors considered the measure to be good if no collapse nor any arthrosis occurred in the wrist.

Razemon (1984) reported RSO data involving 28 patients, of whom 12 were followed for more than 10 years. Distribution in Decoulx's classification was stage I/5, II/4 and III/4. The results were evaluated as excellent in 8, good in 3 and fair in one patient.

Kuebler and Segmüller (1985) used the "Niveau Operation" in 19 patients with Decoulx's stage-II to -III disease. Follow-up time ranged from 4 to 17 years. After two years of follow-up, 79% were painfree, three-quarters of the patients' grip strength was ≥75% of the strength of the healthy side. Everyone continued their former jobs, and 10 patients did manually heavy work.

Rajani et al.(1985) published the results of six patients with RSO using the Axelsson technique. Their average age was 35 (18-44) years, all of them did heavy work, and their symptoms had averaged 5.3 years. The disease was on the dominant side for four. Four had a Ståhl rating of stage III, and three of stage IV. The mean ulna minus variance was -2.5 (0-5) mm. The shortening was 4.8 (3-6) mm, and the follow-up period 4.1 (1.6-5.6) years. Five patients were completely painfree and returned to their former jobs. Extension-flexion improved on average 65° (50° -90°) ad 115° (100° -135°). Grip strength was 90 % of the strength of the healthy side. At follow-up, Stage 0 (normal) was in one, stage II in one, stage III in one, stage IV in two, and stage V in one patient who had developed arthrosis. Lunate's sclerosis decreased clearly in two patients. The result was considered good.

Glas et al. (1988) published on 11 patients with a follow-up time of 10.3 years. Two had Decoulx rating Stage IV and nine Stage III. In nine patients, the condition was good for pain, the pain was mild during heavy work. Total ROM improved by 59.5°, however, being on average 51° worse than in the healthy hand. Strength was good in eight patients. Lunate structure improved in eight patients, but the shape of the lunate was not corrected. The two previously primary arthrosis cases were aggravated, and two developed an arthrosis. One patient had to change his job. These results were compared with those previously published and with the same criteria. Nine patients (82%) had good results after ten years.

Nakamura et al. (1990) investigated those factors affecting the outcome of the RSO. The average duration of 23 patients' follow-up was 5.5 years. Stage was defined by CHR, arthrosis, and Ståhl index. Stage I was Ståhl ≥45, stage II 30-44, and stage III <30. A CHR difference 0.03 compared to the healthy subjects was stage IV and arthrosis was stage V. The final result was evaluated by the satisfaction criteria of Lichtman (1982), as satisfactory/unsatisfactory, and Nakamura's rating, which includes pain, grip strength, ROM (maximum 21 points), and radiologic situation (maximum 9 points). RSO was done in Z-model form and irrespective of ulnar variance, also in neutral and plus variance. Pain was relieved in 20 patients. Ten (43%) were painfree, ten had mild pain in the more burdensome tasks, and three during mild strain. DRU joint pain was present for three patients, and they had initial variance +1, the shortening being more than 4 mm. With Nakamura's scoring, the result was excellent 9, good 4, moderate 8, and bad in one patient; by Lichtman's criteria, 83% were satisfactory. Extension-flexion improved by an average 16° and grip strength improved from 62% to 89% of the contralateral.

Radiologically, lunate sclerosis improved in 11 (48%) patients and worsened in 5 (22%). Cystic changes were corrected in 61% and worsened in 4%, fragmentation improved in 43% and deteriorated in 17%. The result was better in patients under age 30. Neither stage nor ulnar variance affected the outcome. With a radial shortening more than 4 mm, the result was significantly reduced compared with an optimal shortening of 1.5 to 3 mm. The authors note that the indication for shortening osteotomy was decompression of the lunate and not primarily equalization of the variance. In Japanese population, neutral and plus variance were more frequent than a minus variance.

Messina (1990) published on 28 patients with a follow-up time of 5 to 16 years; 25 were men, and in age ranged from 19 to 48 years; 26 had a minus variance. Ståhl rating was stage I in one, stage II in 6, stage III in 15 and stage IV in 6 patients. The shortening of the radius was 5 to 8 mm. Fixation was performed with Kirschner wires, after-care was a plaster cast for 3-4 weeks. Their movement improved, the pain decreased, and the lunate's situation stabilized.

Rock et al. (1991) reported on 16 patients who did not benefit from conservative treatment. The minus variance was a mean 3.3 (2-4.5) mm; one had neutral variance. Any ulna plus variance or arthrosis was a contraindication to surgery. Six had Lichtman stage II and six stage III, and four had stage IV. Their mean age was 28 years, and they included 14 men. The dominant side was affirmed in eight cases. The transverse metaphyseal osteotomy was used in the surgery, and the fixation was performed with a DC-plate dorsally. The follow-up time was 4.5 (2-6.5) years, with 13 patients becoming completely painfree. Flexion improved in 10 patients a mean 15° and grip strength improved by 20% to 30% and was 50% to 70% of the contralateral. There were no problems with the DRU joint, not even in healing of the osteotomy. The plate was removed from 12 patients. In one patient initially in stage III, the changes in the lunate progressed. The authors note that the result was equally good at all stages of the disease, and, according to them, the RSO indications could be extended to fragmented lunates and localized arthrosis cases, as Eiken and Niechajev had also stated (1980).

Weiss et al. (1991) had 30 wrists, all at Lichtman stage I to IIIB. The mean age of their patients was 39 (17-41) years, and their symptoms had lasted for a mean 15 months; 18 were men, 11 women, one case was bilateral. In 16 cases, the disease was on the dominant side; 19 patients were right-handed; 45% had a history of trauma, three of whom had suffered a lunate fracture. On average, the minus variance was 2.8 (2-6) mm. In 10 patients, the diagnosis was confirmed by MRI or bone scanning, or both. There were 3 stage I, 7 stage II, 16 stage IIIA, and four at stage IIIB. Osteotomy was done through a volar approach and fixed with a 6-hole DC- plate. Mobilization was started on the first postoperative day. The follow-up was performed 3.8 (2-9) years after surgery. Pain was reduced in

87% of patients and 70% were completely painfree. The average extension was 51° (increase 32%), flexion 55° (increase 27%), radial deviation 19° (increase 30%) and ulnar deviation 31° (increase 41%). Grip strength ranged from 12.7 to 39 kg.

Radiologically, in 10 wrists, revascularization was found to be a sign of improvement in the lunate`s structure, in 15 wrists the situation was unchanged, and 5 (17%) lunates had collapsed. The Ståhl index was preoperatively an average of 0.41 and at follow-up 0.38. No significant difference was radiologically observable in lunate indices. Two patients had a complication: one had a too-excessive RSO causing ulnar abutment, and the other osteotomy developed a non-union. Both were repaired by reoperation. In a third patient, the lunate collapse worsened, and intercarpal joints became arthrotic. At two years, that lunate was removed, and a scaphocapitate arthrodesis was made, which did not relieve the pain. The authors note that no substantial difference existed in the lunate, when compared to the preoperative situation, even though the clinical outcome was good. Although osteotomy may inhibit further degeneration, no apparent improvement in the healing of the lunate has occurred, although in ten patients the lunate appeared to be more normal. The amount of shortening may prove irrelevant. Two patients had postoperatively negative ulnar variance, and still the result was good. Osteotomy could therefore also be applied to neutral variance if the shortening is mild (maybe 2 mm). In stage IIIB, the shape of the lunate or fixed rotation of the scaphoid cannot be expected to improve. However, in four stage-IIIB patients, the result was promising at the 3- to 5-year follow-up. In the case of arthrosis, no osteotomy should be performed, according to this very well-documented study.

Matsushita et al. (1992) investigated the effect of radius inclination on 10 lunatomalacia patients with RSO. The average follow-up time was 1.9 (1.1-4.8) years. The degree of lunatomalacia was in one patient stage II, in eight stage III and, in one stage IV. In nine, pain was relieved. Grip strength was 82% of the contralateral, thus improving by 41%. The overall ROM improved from 71% to 82% of the contralateral. There existed no significant differences between carpal indices; the difference was between the inclination of the lunate fossa and the repair of the lunate structure. If the inclination was more than 12° (four patients), the result was significantly better than the three with lower inclinations. The averages in the groups were 16° and 8°. The corresponding inclination angles of the radius were 31° and 22°. The investigators' discussion referred to the Linscheid study, where inclination of the lunate fossa averaged 14° (range, 0° -20°). They considered whether RSO should be combined with a medial wedge-closing osteotomy or a lateral-opening osteotomy done, if preoperatively the lunate fossa`s inclination is less than 12°. It should be mentioned that, in Mirabello`s et al.study (1987), "a flat radius" could predispose to Kienböck's disease.

Nakamura et al. (1993) used magnetic resonance imaging in estimating the blood supply of the lunate in conjunction with RSO. For at least one year, 24 patients were monitored with a series of images. Their disease stage was I in one, II in nine, III in eight, and stage IV in six according to the Lichtman classification. Nine patients had a neutral or minus variance and were subjected to RSO, ten had a neutral or plus variance, treated with RCWO. Five were treated with splint or bandage for 2 to 3 months. The follow-up time was a mean 1.9 (1-3) years. All had MRI prior to surgery and half underwent a control scan at one year. The outcome after RSO by Nakamura scoring was excellent or good for eight of these nine, and after RCWO for six. The result after conservative treatment was good in one, moderate in three, and poor in one. Lunate architecture improved in the RSO Group in five of the nine and in the RCWO Group in six, but in the conservative group in none. Signal intensity improved at follow-up in 17 of 19 after operative treatment, and in 9 cases it was normal or almost normal. For eight of these, the lunate architecture also improved. Change in intensity did not correlate with clinical state, but with improvement in lunate structure. The author noted that the improvement in signal intensity associated with the lunate`s vascularization. In the early phase, especially in the T2-weighted image, the change can be seen first.

Fischer et al. (1993) wrote an overview of the so-called niveau operations. They founded in previous publications good results results from RSO and the ulnar lengthening were similar, complications in the ULO procedure were more. A lengthening of 5 mm in the ulna reduced the load on the lunate by 60%. According to the authors, the niveau operation is suitable for stage I to III cases, possibly also for stage IV.

Amillo et al. (1993) published data on 12 patients from RSO. Of the patients, 11 were men, their mean age was 25 (18-57) years, and the follow-up was 5 (3-9) years. Everyone was right-handed, the disease affected the right hand in seven. Seven were doing heavy work, and six had had a hyperextension trauma to the wrist. The ulnar variance was -4.5 (0- to -8.5); CHR 0.50 (0.44-0.56), with no instability. Eight had a Lichtman rating of stage II, and four had stage III. Osteotomy was performed through a dorsal approach by use of a DC-plate. No complications arose. Six patients became completely painfree and were able to handle their jobs. Of these, five had preoperatively stage II. In two patients, the pain remained unchanged. Wrist movement improved slightly, flexion was 80%, extension 85%, radial deviation 60% and ulnar deviation 60% of the contralateral. In two, the CHR as well as the lunate structure improved. In four patients, lunate sclerosis decreased, five had no change, and one lunate worsened, leading to a wrist collapse. In ten patients, the outcome was judged to be good, eight of whom were primary stage II, and two were bad. The result corresponded to the published results after the ulnar lengthening.

Condit et al. (1993) compared in their retrospective study RSO- to STT arthrodesis. The RSO group had 14 patients, and in the STT group were 9 patients these groups had 62 and 54 months of follow-up. The results were compared with a scoring in which the wrist function, motion, and grip strength force received the same maximum score (3 points of 9). The groups were comparable as to both clinical and radiological parameters. Radiology was evaluated by Swanson's rating. In neither group was the lunate collapse blocked. After the RSO, all 13 employed and working patients returned to their work, but after the STT only half the patients did. ROM improved in the RSO group by 17% and deteriorated in the STT group by 14%. Grip strength improved by 44% and 10%, respectively. A good or excellent result was achieved in the RSO group in eight patients and in the STT group in three. Three patients with STT arthrodesis were later subjected to wrist fusion, two, due to a non-union and one due to a lunate collapse. In one in the RSO group, the result was poor. The authors' evaluation was that the reason for it was a rotation failure of the distal radius at surgery. The only significant item was the radioscaphoid angle. Any angle more than 60° worsened the result, and RSO did not give the desired result.

Weiss (1993) presented a review of RSO results and detailed operative technique using a volar dynamic compression plate. The results were good: the pain was relieved, and the ROM and grip strength improved. Excessive shortening must be avoided due to the incongruency of the DRU joint, and there is no need for full neutral variance (2-3 mm is sufficient). The procedure is also suitable for stage III, but not if the wrist has already developed arthrosis. According to Weiss, it would also be possible to use RSO in the neutral variance and in the slight plus variance as well. Long-term effects are unknown. The external architecture is unlikely to be repaired. The procedure-related morbidity is low, a nonunion occurs in 3% to 4%. The method is extra-articular and does not prevent possible later procedures to the wrist.

Nakamura et al. (1995) presented action mechanisms of radius osteotomies and the techniques used. RSO decompresses the lunate by transferring the load to the radioscaphoid and ulnocarpal joints. Use of a so-called rigid-body spring model showed that radial closing wedge osteotomy also reduces axial load in the capitolunate and radiolunate joints (Watanabe et al. 1993). Osteotomy reduces ulnar translation of the capitate and causes increased radial translation of the lunate, thus causing increased radiolunar contact area. The lunate's revascularization is often seen as a repair of sclerosis and cystic changes. Findings support the view that revascularization occurs in the lunate. Nakamura emphasizes osteotomy as a decompressive measure; its primary purpose is not to overcome the variance. In Japan, only one-third of lunatomalacia patients have a negative ulnar variance, and radial closing wedge osteotomy is also used in neutral and positive ulnar variance.

DeSmet et al. (1995) published RSO results in 17 patients after 4.5 (1-7) years of follow-up. These comprised 11 men and 6 women, average age 37 years. In seven patients, the Lichtman stage was II, in four III, in six IV. The preoperative ulnar variance was on average -0.6 and postoperatively +1.5. In 11 patients, the variance was positive and in 7 of these + 2 - + 4, causing limited pronation, averaging 59% and ulnar deviation 60% of contralateral. Nine patients had occasional mild pain, five, moderate but none had persistent or severe pain. The Cooney score (MWS) was <65 in four and 65-80 in ten patients Grip strength was 75% of contralateral. Lunate's progressive change occurred: stage IV was 9, stage III 7, and stage II one with preoperatively stage II. Nine patients had arthrosis or impaction syndrome in the DRU joint. The researchers realized that RSO should not be done if the wrist has +1 mm of ulnar variance.

Quenzer et al. (1997) published on 68 RSO patients with an average follow-up time of 4.3 (1-11) years. Male patients were 47 (69%), the largest age group was 20-29 years of age, 97% were right-handed, and in 63%, the disease affected the dominant side. About half had a history of trauma. In addition to osteotomy, 13 patients had a free bone transplant, 9 patients had osteosynthesis of the lunate, and 12 had undergone various treatments of revascularization. Four of them had delayed bone union but required no intervention. In addition, there were two injuries to the EPL tendon (9%). At one year of follow-up, 93% of patients considered the situation to be better, and 43% were painfree. ROM improved in 52% and worsened in 19%. Grip strength improved in 74%. Two patients later developed ulnocarpal abutment syndrome. Additional measures were required for 25 patients, but among these, clinical results did not significantly differ from those of patients treated with osteotomy alone. Standard X-rays revealed no progressive wrist collapse or ulnar translation. Radial inclination was slightly increased (4°) and five patients had bone formation in the lunate fossa. For at least one year, 35 patients had been radiologically monitored. In 12 patients (34%), lunate density and fractures improved, and joint spaces were maintained: 25 of the patients had only RSO and 5 of them (20%) showed healing of the lunate. For 46%, the lunate remained unchanged, but in 20% it collapsed further. Bone density for 35 patients improved in 40% and deteriorated in 14%. Lunate collapse improved in 31% and in 66% remained unchanged. Fragmentation improved in 5, was unchanged in 28, and worsened in 2 patients. Of the 35, 8 (23%) developed arthrosis, usually in the radioscaphoid region (styloid process), and all had long-progressing collapse. CHR improved in 29%, was unchanged in 43%, and deteriorated in 29% of the patients. Radiologically, no statistically significant difference was observable between those treated with revascularization and RSO and those with only RSO, but the appearance of the lunate was in 55% improved. Free bone transplantation, except for one case, was not found to be beneficial, nor did temporary fixation of

the lunate. Overall, osteotomy scores were good in most patients. With regard to revascularization, no reliable evidence emerged, and further studies are necessary.

Salmon et al. (2000) compared the results of conservative treatment and RSO. Patients came from three centers in the northeast of England, and surgery was performed by three senior surgeons. There were 15 patients in the RSO group, 4 of whom had stage II, and 11 had stage III disease. The average age was 29 (19-50) years. Of the 15, 14 participated in a clinical follow-up study. There were 18 conservatively treated, 5 with stage II and 13 with stage III disease; 17 participated in clinical research. The average age was 33 (21-70) years. In both groups, the monitoring time was 3.6 (1.5-9) years. Conservative treatment was not defined more precisely. In the conservative treatment group, the ulnar variance was -1.7 (1.0-3.0) mm, and in the operated one -2.5 (0 - -4.5) mm. At follow-up, pain scoring (0-10) was at rest 0.5 (0-4.0) in those surgically treated and 2.8 (0-6.5) in those conservatively treated. At worst, the pain was in the RSO group 3.0 (0-8.0) and in the conservatively treated patients 7.6 (4.0-10.0). ROM in surgically treated patients was 73% and in conservatively treated patients 61.5% of the contralateral side. There was no restriction with prosupination. Grip strength was in surgically treated patients on average 75% and in the conservative group 61% of the contralateral.

Radiological progression was rapid in six conservatively managed patients already during the 6- to 18-month follow-up. In the operated group, the change was slower. The RSA increased in the conservative group three times more than in the surgical group. A lunate fracture healed in one conservative-treatment patient (8%) and in three (27%) surgical patients. The lunate flattened in 83% in the conservative group and in 64% in the surgical patients. Carpal collapse increased in 75% in the conservative group and remained unchanged in 73% in the surgical patients. For one in the surgical group, an arthrodesis was made due to arthritic changes visible in wrist arthroscopy. In the conservative group, arthritis changes occurred in two patients. In the conservative group, three wrists at Stage II remained the same, and one became better. The researchers stated that stage II could be initially managed conservatively. RSO is effective in patients with troublesome pain and signs of progressive wrist-collapse.

Koh et al. (2003) published the results of the RSO's 10-year follow-up and assessed whether the result of the five-year follow-up remained. In a retrospective study of 25 patients, 18 men and 7 women, the disease was on the dominant side in 20 (Table 4). Age averaged 33 (11-55) years, and one child had also undergone surgery. The monitoring period was 14.6 (10.4-21.6) years. Manual workers numbered 18, and, the rest were athletic, active students. Ten had RSO and 15 had radial closing wedge osteotomies (RCWO). In both, a step-cut osteotomy was the choice. Radiological changes were graded on a scale of 0 to 10, according to the height of the lunate, sclerosis, cysts, fragmentation, and bone trabeculae as well as

congruence of the radiolunar joint. Pain was evaluated on the scale: no pain, mild, moderate, and severe pain. The results were evaluated by Cooney and Nakamura's scoring systems. Patients were divided into two more groups by age, below or over 30. The results were compared to the 5-year results of the same patients. Preoperatively the pain was mild in 3, moderate in 15, and severe in 7 patients. At the final follow-up, 12 patients were painfree (48%), 12 had mild pain, and one had moderate pain: 22 returned to their former jobs. ROM and the grip strength improved significantly, from 67% to 82% and from 62% to 85%, respectively.

There were no significant differences between the 5- and 10-year follow-up. Nakamura Score was in 68% excellent or good and Cooney score in 96%. Preoperatively, one had stage I, four stage II, 11 stage IIIA, and six stage IIIB. Stage remained unchanged in 11 patients, worsened in 9 and improved in 2 patients. There was no significant change in CHR and Ståhl indices. At five years, 11 patients had arthrosis (54%) and at 10 years 16 (73%). Nakamura's scoring values at age <30 years were better than >30 years, which also takes into account radiologic changes in the lunate. Osteoarthritis did not correlate with clinical outcome.

Iwasaki et al. (2005) published RSO results in 11 teenager's age of 15.9 (11-19) years. The monitoring period was 4.1 (1-9.8) years. Six were male patients, and another six had a history of trauma. Three had Lichtman stage II, two IIIA, and six IIIB. RSO was done in ulna minus variance, and a RCWO in two with ulna neutral / plus variance. All of them had previously undergone an MRI study. The surgery was performed through a volar approach, and each osteotomy was fixed by a DC-plate, of which 10 were later removed after the osteotomy had healed. The results were evaluated by modified Nakamura scoring, which takes into account improvement of pain, of grip strength, and extension / flexion. In addition to the X-ray images, eight patients underwent MRI at follow-up. Ten patients were painfree, Nakamura scoring averaged 18.8 (4-21), and the result was excellent in ten and moderate in one. This patient was the oldest, a 19-year old, stage IIIB with RCWO. Wrist extension-flexion improved significantly (80.5° and 132°) as did grip strength from 37.7% to 81.5% of the healthy side. The Lichtman stage improved in eight, remained unchanged at two and was worse in one. MRI signal intensity improved in 7 of 8 patients. No overgrowth of the radius was evident within this follow-up. The discussion referred to two case reports where the result was good with immobilization. Osteotomy was still a success.

Zenzai et al. (2005) published RSO results for 14 patients with a follow-up of 19 (13-25) years (Table 4).Their mean age was 31 (15-58) years and ten were men. Ten did hard manual work. On the Lichtman scale, five were stage II, five stage IIIA, and four stage IIIB. The surgery was aimed to achieve 0 to + 2 variance. RSO was done for four with minus variance and for six with neutral variance. Four patients had ulna-plus variance and underwent RSO by 3 mm and an ulnar shortening

adequate to the variance. Osteosynthesis was performed with a DC- plate. At follow-up, nine were painfree (64%), four had mild, and one moderate pain. The Cooney score was preoperatively on average 44 and at follow-up significantly better at 78. Extension and flexion improved significantly from the preoperative, with an average extension of 87° and a flexion of 78° of the healthy side. Grip strength was 86% of the contralateral, preoperatively 74%, a difference that was not significant. Lichtman stage deteriorated in three patients. Radiological indices (CHR, Ståhl, RSA, SLA) did not show significant differences. One patient had arthrosis of the midcarpal joint, and five had arthrosis of the radioulnar joint. One patient had a restriction of pronation even before the procedure. The authors stated that the long-term outcome was excellent or good in six and moderate in eight patients. Radiological indices did not reveal any deterioration during the follow-up period, meaning that this operation prevented carpal collapse. Only 40% of the original 35 patients participated in the study.

Raven et al. (2007) reported RSO`s long-term results after an average of 22 (16-31) years of follow-up (Table 4). Of the 12 patients, 9 of them attended the follow-up. Their mean age was 31 (20-44) years, and half the patients had the disease in their dominant hand. Everyone had an ulna minus variance. The Lichtman stage was in two II, four IIIA, one IIIB, and two were missing. The shortening averaged 3 mm, and dorsal osteotomy was fixed by a DC-plate. At follow-up, six patients were painfree, two had heavy pain during hard labor, one continuously. VAS score was 2.4 (1-10), VAS satisfaction rating 2.2 (0-8), and DASH score 14 (0-68). Eight patients returned to their previous occupations. The average extension / flexion was 59° to 67° (79-103% of contralateral) and ulnar / radial deviation 39° to 25° (78-82% of contralateral). Grip strength was 90% of contralateral.

In two patients, the Lichtman stage worsened, two stage IIIA became IIIB. The change had taken place already at ten years' follow-up. CHR remained unchanged at 0.55. There occurred no complications. One patient did poorly (DASH 68). He had preoperatively stage IIIB, and although radiological deterioration did not occur, his clinical outcome did not improve much. The authors recommend RSO in Kienböck's disease stage I-IIIA in the minus variance of the ulna.

Kakinoki et al. (2007) published data from three patients with Kienböck's disease progression after RSO. Two had RSO and one RCWO; all of them had Lichtman stage IIIA. The progression of the disease continued, the wrist was painful, and the grip strength was poor, on average 19% of the contralateral, extension-flexion was restricted, averaging 37% of the contralateral, and in two the disease had advanced to stage IIIB. A capitate 2- to 3-mm shortening osteotomy was made, the capitate was fused to the hamate, and the lunate was vascularized with the fourth and fifth ECA (extensor compartmental artery) 5 to 8 months after the osteotomies. After an average of 20 months of follow-up, the situation was better.

No complications occurred. One wrist was painless, and two had slight strain pain. Grip strength improved on average to 77% of the contralateral. The authors warned of the development of arthrosis, because the joint surfaces were not congruent, and the cartilage of the lunate was damaged.

Altay et al. (2008) investigated RSO's suitability for Lichtman stage IIIB. They had 13 stage-IIIA and 10 stage-IIIB patients with a follow-up period of 7.1 (2.1-12.2) years. Seven patients had neutral variance, and the others had minus variance. The average age was 30.7 (18-46) years. The disease was in 17 patients in the right wrist and in 16 on the dominant side. Twenty patients did hard manual work. Surgery was performed through a volar approach, and osteotomy was fixed by a DC-plate. The average shortening was 2.6 (2-4.5) mm. Immobilization lasted for a total of 8 weeks. Complications were observable in one patient with delayed bone union, and additionally there occurred two superficial infections, two ulnar pain states, and two cases of tenosynovitis. The groups were compared with Nakamura scoring, showing no significant difference between the groups (IIIA 14.3 vs. IIIB 13.3). Of these patients, six (26%) were painfree, twelve had pain during exertion (52%), and five (22%) had slight pain during daily activities. Extension-flexion improved in both groups significantly, with no significant difference between groups (IIIA 102.2° and IIIB 92.3°). Grip strength was in group IIIA 82.3% and in IIIB 80.2% of the values of the contralateral side. Otherwise, the groups were not compared pre- and postoperatively. In summary, RSO improved hand function in stage IIIB disease.

Watanabe et al. (2008) published on 19 patient's RSO data, of which 12 participated in the follow-up examination (Table 4). Of them, 10 were men, the mean age was 39 years, and the disease was in the right wrist in 9 patients. Ulnar variance was positive in five (2-6 mm), neutral in four, and negative in three (-1 mm) patients. Lichtman stage was II in six, IIIA in three, and IIIB in three patients. An average shortening was performed of 3 (2-5) mm. For three plus variants, the ulna was also shortened by 3.7 (3-4) mm. The follow-up period was 21 (14-28) years. In 12 patients with pain, the situation improved, and at the time of the study, six were painfree (50 %), and mild pain occurred in six patients. Seven patients had pain in axial compression and five during wrist palpation. The DASH score averaged 8.0 (0-23) and the modified Mayo wrist score 82.9 (63-100). In ten patients, ROM improved. Flexion improved from an average of 30° to 58° and extension from 46° to 55°. Flexion was on average 81% and extension 82% of contralateral, radial deviation 88%, ulnar deviation 72%, pronation 85%, and supination 96%. Grip strength improved from 18 kg to 28 kg (88% contralateral). CHR and Ståhl indices significantly decreased (averages: 0.52 vs. 0.51 and 0.43 vs. 0.40 pre- vs. postoperative). In six patients, Licthman stage worsened, stage II in four to stage IIIA and two from stage IIIA to IIIB. The radioulnar joint had preoperative degeneration for one and at follow-up for three patients. In stage IIIB,

DASH (mean 11) and modified Mayo wrist score (mean 75) were significantly worse than in stages II and IIIA. Radiocarpal arthrosis did not develop in anyone, and the change in the DRU joint was not associated with any positive variance, with results similar to those with minus variance. The authors found as deficiencies the small number of patients and the fact that almost one-third of the patients dropped out of the follow-up study. RSO was a reliable alternative to the treatment of lunatomalacia of stage II-IIIA and a viable alternative also for treating stage IIIB with its long-term outcome being more limited.

Takahara et al. (2009) published, in addition to Watanabe`s article, their operative technique. The approach was volar, and in the minus variance, the radius was shortened by transverse metaphyseal osteotomy. In the plus variance, radial closing wedge osteotomy was performed at 5 to 10 degrees, with an ulnar shortening of approximately 1 mm and radially about 3 mm. The fixation occurred with a T-plate, using compression. The wrist was immobilized by splint or plaster cast for 4 to 6 weeks.

Calfee et al. (2010) compared RSO outcome between stages II / IIIA and stage IIIB. The exclusion criteria for the data were age less than 16 years, a severe prior wrist injury and inflammatory arthropathy. Patients numbered 45, and five of them were unreachable, with nine patients refusing the follow-up examination. The average follow-up for stage II-IIIA was 6.0 and for stage IIIB 6.4 years. They included four stage II, 13 (one bilateral) stage IIIA, and 14 stage IIIB patients. No difference in demographic data existed among the patient groups. Ulnar variance was preoperatively, in the stage II / IIIA group, -1.9 mm, and in the IIIB group, -2.8 mm; these were at follow-up 0.2 mm and -0.3 mm. QuickDASH was in Stage II / IIIA group 12 and in IIIB 15, MWS 87/84, pain VAS 1.7 / 1.2, and function VAS 2.1 / 2.6. There were no significant differences between the two groups. Flexion was on average 52°/53°, extension 54°/49° and as a percentage of the contralateral respectively 85/81% and 93/84%. The only significant difference was in ulnar deviation: 35°/25°. The grip strength in the II / IIIA group was 28.9 kg (85% of contralateral) and in IIIB 32.8 kg (77%), the difference was not significant. CHR and RSA were significantly lower in stage IIIB, CHR 0.53 vs. 0.46 and 53.2° vs. 64.6°. Two patients in the IIIA group developed ulnar abutment, which was treated with an ulnar shortening osteotomy. In the initial situation, one had a 0-variance and the other +2 mm variance, after surgery +2 and + 4-mm variance.

In the IIIB group, one patient had a stage IV illness and the wrist remained painful. In stage II / IIIA, the disease progressed in six patients. Despite progression, the clinical outcome was good in both groups. A better functional result correlates with wrist mobility and a smaller radioscaphoid angle. There was no correlation with the degree of disease, CHR or CUDR. RSO appeared to be an appropriate treatment in lunatomalacia stage II / IIIA. Clinical results were similar in stage

IIIB disease, although CHR was permanently lower and SRA higher. According to the authors, RSO can be done in the stage II, IIIA and IIIB Kienböck. In the discussion, the authors stated that lunatomalacia is so rare that reliable information on effective treatments and long-term results is almost impossible to obtain.

Nakamura et al. (2011) discussed the indications, techniques, and results of RSO in their review article. Several studies have shown long-term relief of pain and improvement of grip strength and wrist mobility. Osteotomy has improved vascularization of the lunate (Nakamura et al. 1993). RSO decompresses the lunate, but there is no similar decompression effect in RCWO. Instead, the radius coverage of the lunate is improved and, consequently, the pressure on the radial portion of the lunate decreases. The authors report that patient age, ulnar variance, disease stage of Lichtman, and lunate osteoarthritis should be taken into account when deciding osteotomy indications. In the negative ulnar variance, RSO was recommended and RCWO in neutral or plus variance. In stages I to IV at the age of 15 years and younger, the authors recommend plaster-cast treatment, possibly in addition to temporal STT arthrodesis and selective RSO. For 15- to 25-year-olds, the authors also recommend osteotomy in stages I to IV and for over 25 years of age in stages I to IIIA. In the latter case, also in stages IIIB to IV, if the lunate is congruent in arthroscopy. If the lunate is deformed in arthroscopy, osteotomy is not advisable. Osteotomy was also not performed if in stages IIIB to IV the lunate had been fragmented and not when the patient was only mildly disabled, and the extension-flexion motion and grip strength was over 80% of the contralateral. RSO was done through Henry's approach, and osteosynthesis was performed with a compression plate. Radial wedge osteotomy was performed radially with a step-cut technique and fixation with a compression plate.

Blanco and Blanco (2012) published the results of the RSO in which osteotomy was performed without shortening of the radius. Of 14 patients, 11 attended the follow-up study conducted after at least 10 years of follow-up (Table 4). The patients were male manual laborers, and right-handed, in age ranging from 18 to 42 years. One patient had neutral variance, the others minus variance averaging -1.8 (-1.5 to -3) mm. Lichtman's classification was in three stage II, in five stage IIIA, and in three stage IIIB. Osteotomy was performed with a compression plate. The plaster cast was worn for 4 to 5 weeks, and all united without complications. Preoperatively, one patient had mild pain, four moderate, and six severe. At follow-up, six patients were painfree (54.5%), three had mild, and two had moderate pain. Active movement of the wrist improved by 30% (73° / 96°) and grip strength improved from 65% to 80% of the contralateral (38/52 kg). Ten patients returned to their former jobs. Radiologically, in three lunates, sclerosis occurred, and in two, fragmentation. Ulnar variance did not change. No arthrosis was noted in the radiocarpal joint. One Lichtman stage-IIIA patient worsened to IIIB. CHR was preoperatively 0.52

and at follow-up 0.53. The authors note that the procedure provided long-lasting pain relief, and grip strength improved. The effect of osteotomy is based on the beneficial effect on the blood supply to the lunate.

Rodrigues-Pinto et al. (2012) published on 18 patients an RSO study comparing results between Lichtman stages II to IIIA and IIIB. Their 18 patients had a follow-up time of 10.3 (4-18) years (Table 4). In these 13 men and 5 women, the disease was on the dominant side in 13. Age at surgery averaged 31.6 (16-52) years. Pain was severe in 12 patients and moderate in 6. Fifteen had negative ulnar variance and three neutral. Lichtman stage was II in one, IIIA in 11, and IIIB in 6. Ulnar variance was negative in 15 and neutral in 3 patients. The procedure was done by Henry's volar opening, and the osteotomy was fixed with a compression plate. Shortening was no more than 2 to 3 millimeters and in neutral variance 1 to 2 millimeters. There were no complications. In three patients, the plate had been removed later. Pain was assessed on the VAS scale (0-10), with 12 patients (67%) painfree, one with VAS 1, and five with VAS 2. Nakamura scoring served to measure function, averaging 24.4 (20-29) points and DASH score 14.9 (0-35). Motion significantly improved from 76.8° to 100.5°, extension being 71.4% and flexion 79.4% of the values of the contralateral side. Grip strength was 73.2%, respectively. Fifteen returned to their former jobs or activities, two changed their jobs, and one retired because of wrist pain.

There was no change in the Ståhl index (0.32 vs. 0.31) or CHR (0.52 vs. 0.52). The only significant differences between the II / IIIA and IIIB groups were in relative grip strength (79% vs. 63%), in Nakamura scoring (25.5 vs.22.5), and in DASH scoring (8.67 vs. 23.33). No difference was visible in the radiology of the groups. In the discussion, the size of the group was judged inadequate for comparison. However, pain was relieved, and motion improved also in stage IIIB. The authors noted that RSO is a valid option also for those patients. Patient information was important in these patients.

Afshar and Eivasiatashbeik (2013) published data from 16 Kienböck patients, 9 of them treated with RSO (Group 1) and 7 with a vascular graft from the distal radial (Group 2) by use of the 4 - 5 extensor compartmental artery. In that retrospective study, RSO monitoring was a mean 6.4 years and revascularization 6.5 years. The RSO group had six men, whose age at the time of surgery averaged 24.1 years. Disease degree was stage II in two and stage IIIA in seven. In group 2, mean age was 22.5 years, six of these seven were female, and degree of disease was stage II in three and was stage IIIA in four. The ulnar variance in group 1 averaged -1.9 mm and in group 2, -0.3 mm, the difference being significant. Otherwise, the groups were similar. In group 1, two patients were painfree, five had mild, and two had moderate pain. In Group 2, three patients were painfree, three had mild and one moderate pain. Nakamura score was 20 in group 1 and 23 in group

2. MWS was, in group 1, 81 and in group 2, 89 this difference being significant. Neither wrist motion (88.8% vs. 88.5%) nor grip strength (31.4 kg / 74% vs. 30 kg / 95%) significantly differed. In the RSO group, the Lichtman stage improved in three, deteriorated in one, and remained unchanged in five. In eight patients, the lunate structure improved. CHR and Ståhl index remained unchanged in seven, in one, improved, and in one, declined. One patient developed arthrosis. In the vascularization group, Lichtman stage improved in one, the others' stage remained unchanged, with lunate structure (sclerosis, cysts, fragmentation) became better. Indices did not change, and no arthrosis was detectable. In summary, the authors note that there was no significant difference in results between treatment groups.

Matsui et al. (2014) presented their series of 10 patients (one bilateral) who underwent RSO (Table 4). Disease degree was Lichtman stage IIIA in two, IIIB in eight and IV in one wrist. The monitoring time was an average 14.3 (10-21) years. Nine patients had ulna minus and two had neutral variance. No complications reported. At follow-up six wrists were painless and five had mild pain. DASH score was 5 (0-18) and MWS 92 (80-100).The mean extension and flexion improved significantly, mean extension was 71° and mean flexion 55°. Grip strength improved significantly to 90% compared to the healthy side. Radiologic indexes did not change and no arthrosis was encountered. The material included two children, aged 11 and 13 years.

Van Leeuwen et al. (2016) compared, in their 48-patient series, the radiographic progression at least once a year by their X-ray images between RSO and non-surgically treated Kienböck patients. Measurement of radiological indices was performed on the first postoperative pictures and for those conservatively managed, their first images. Patients were recruited from two hospitals and comprised 20 who underwent surgery and 28 who were conservatively treated. The interval between the first and last X-ray images was a median 3.5 (2.4-5.5) years. In the RSO group, two patients had also revascularization during the surgery, and four had later PRC. In the conservatively treated group, one had later RSO and two, PRC. For measurements of these cases, the last preoperative pictures were used. In CHR, no significant difference emerged between the groups. The Ståhl index for the entire material decreased, but with no difference between treatment groups. In both groups, CHR was impaired in 50% of patients. The Ståhl index worsened in the RSO group in 60% and in the conservative treatment group in 68%. RSA made a significant difference in the RSO group, but no difference existed in the other carpal angles. Statistical analysis was done carefully, for example, power analysis of the groups was completed. The study also had significant limitations. Disease phase and stage could not be taken into account, the imaging interval was short for observing the disease's slow progression, and it was impossible to standardize X-ray techniques afterwards. The research raised many questions, among others:

whether the progression of this disease can be predicted by radiology or clinical findings, whether surgery changes its pathophysiology, and whether the result after surgery is better than after conservative treatment.

Luegmair et al. (2017) published RSO data on 36 patients with a follow-up time of 12.1 (5.4-17.5) years. Initially the number of patients was 64, of whom 9 were unavailable, 2 were dead, and 17 failed, for various reasons, to take part in follow-up (Table 4). No additional measures were taken for these 17 patients. The material comprised 13 women and 23 men at a mean age of 30 (15-48) years; 19 patients had the disease on the dominant side, those left- and right-handed were 18 each, 21 patients did heavy manual work, and 8 had a history of trauma. A transverse metaphyseal osteotomy was performed dorsally in 9 patients and volarly in 26 patients. The average shortening was 3 mm, and osteotomy was fixed with a 6-hole DC- plate. Immobilization was 4 weeks, and 34 patients had ulna minus variance and two neutral. All had Lichtman stage-IIIA disease. No complications occurred. Some plates were later removed because of local irritation.

The functional outcomes were evaluated by the Mayo and Nakamura scores, MWS, the modified Mayo wrist score and by DASH score. Pain at rest at follow-up on the VAS scale (0-10) was 0.2 (0-3) and during exertion 3 (0-8). Seven patients were completely painfree (19.4%). The DASH score was 12 (0-52), MWS 75, and the modified modified Mayo wrist score 83. Estimated by the Mayo wrist score, the result was excellent in 4, good in 8, moderate in 23, and poor in one. The Nakamura score was on average 18. With this scoring, the score was excellent for 5, good for 13, moderate for 9, and poor for 3, with 6 patient's data being insufficient. The age or follow-up time of the patient did not correlate with the scoring results. All patients returned to work, but five of them had to modify their previous work.The ROM improved, extension-flexion was 74% of contralateral, and the radioulnar deviation 73%. The difference from preoperative values was significant except in radial deviation. Extension improved from 49° to 57° and flexion from 39° to 54°. Prosupination did not change. Grip strength improved significantly from 51% to 82% of contralateral.

In seven cases of radiological monitoring, the disease progressed to stage IIIB and eight to stage IV. Nine patients had a coronal fracture of the lunate, and four of them improved completely. The ulnar variance was preoperatively an average of -3 mm and at follow-up an average of 0 mm. RSA significantly changed from the preoperative (51° vs. 54°), as did the lunate –covering ratio (60 vs. 67). In the young (aged below 20 years), the Ståhl index was significantly higher than in those over 35 (45 vs. 35). One patient had an ulna abutment that did not require surgery. The long-term outcome was good, although radiological progression occurred in 15 patients. It was estimated that RSO would slow the progression of the disease without providing final healing.

Table 4. Long-term results (mean ≥ 10 years follow-up) of different treatment modalities in Kienböck's disease. Osteotomies

Authors	Year	N patient/ wrists	Treatment	Initial Lichtman stage I / II / III /IIIA / IIIB / IV	Follow-up time, years mean (min-max)	Pain VAS or presented numbers	Grip strength % of contralat.	ROM[1] ext/flex (°) or % of contralat.	DASH[2] mean (min-max)	MWS[3] mean (min-max)	Progression (in Lichtman stage), %.	Arthrosis presence %
Koh et al.	2003	25	RSO 10 RCWO 15	1 / 4 / - /11 / 6 / 0	14 (10-21)	no pain 12, mild 12, moderate 1	85	82%	-	96% excellent or good	41	73 DRUJ 24%
Zenzai et al.	2005	14	RSO 10 RSO+USO 4	0 / 5 / - / 5 / 4 / 0	19 (13-25)	no pain 9, mild 4, moderate 1	86	87°/ 78°	-	78	21	7 DRUJ 36%
Raven et al.	2007	9	RSO	0 / 2 / - / 4 / 1 / 0	22 (16-31)	VAS 2.4 no pain 6, in strain 2, continuously 1	90	79-103%	14 (0-68)	-	22	0
Watanabe et al.	2008	12	RSO 9 RSO+USO 3	0 / 6 / - / 3 / 3 / 0	21 (14-28)	no pain 6, mild 6	88	58°/54° 82% /81%	8 (0-23)	83 (63-100)	50	0 DRUJ 25%
Rodrigues-Pinto et al.	2012	18	RSO	0 / 1 / - / 11 / 6 / 0	10 (4-18)	VAS 0.9 no pain 12, mild 6	73	71%/ 79%	14.9 (0-35)	-	-	-
Matsui et al.	2014	10/11	RSO	0 / 0 / - / 2 / 8 / 1	14 (10-21)	VAS 0.8 no pain 6, mild 5	90	71°/ 55°	5.0 (0-18)	92 (82-100)	-	0
Luegmair et al.	2017	36	RSO	0 / 0 / - / 36 / 0 / 0	12 (5-17)	VAS 0.2 at rest and 3 in strain. no pain 7, mild 26, moderate 3	82	57°/ 54°	12 (0-52)	75	41	22
Blanco and Blanco	2012	11	RO	0 / 3 / - / 5 / 3 / 0	≥10	no pain 6, mild 3, moderate 2	80	96°	-	-	9	0
Wada et al.	2002	13	RCWO	0 / 2 / - / 8 / 3 / 0	14 (10-17)	no pain 3, mild 8, moderate 2	98	59°/53°	-	-	62 (8% better)	31
Trail et al.	1996	20	ULO 16 RSO 4	2 / 10 / 8 / - / - / 0	11 (6-16)	no pain 4, mild 10, moderate 1, rarely 3,	94	56°/56° 84%/82%	-	-	20	65

[1]Range of motion; [2]Disabilities of the Arm, Shoulder and Hand; [3]Mayo Wrist Score. Abbreviations: RSO=radial shortening osteotomy, USO=ulnar shortening osteotomy, DRUJ=distal radioulnar joint, RO=radial osteotomy, RCWO=radial closing wedge osteotomy, ULO=ulnar lengthening osteotomy.

2.11.5.2. Radius wedge osteotomies

Radial closing wedge osteotomy, radial opening wedge osteotomy, and medial closing wedge osteotomy are examined in the treatment of lunatomalacia. Clinical studies are concerned almost exclusively in radial closing wedge osteotomy (Figure 8).

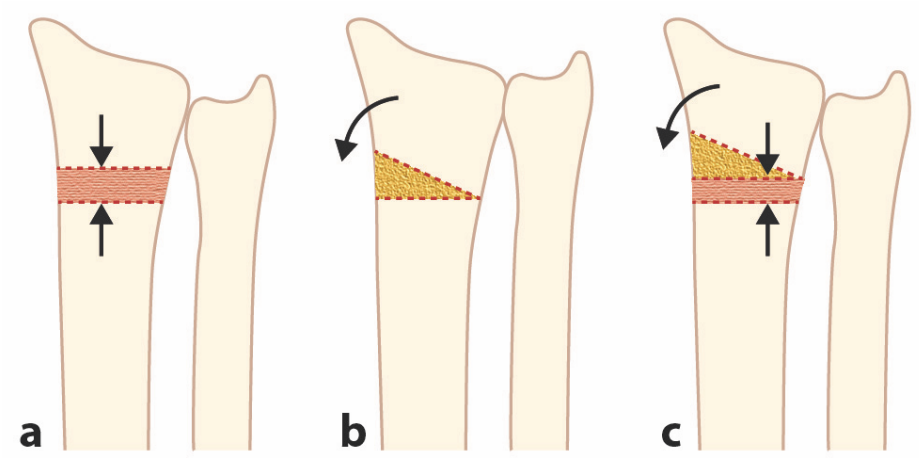

Figure 8. Radial osteotomies.
a. Radial shortening osteotomy (RSO), b. radial closing wedge osteotomy (RCWO), and c. both osteotomies combined. (Tsunoda et al. 1993, modified)

Wedge osteotomies were developed by Tsumura et al. (1982) perhaps because in Japan, the Kienböck patients having a neutral or plus variance is common (Nakamura et al. 1991 and 1995, Tamai et al.1993). In this case, the indication for the RSO may be limited because of possible ulna abutment and possible incongruence of the DRUJ.

Watanabe et al. (1993) investigated the effect of radial closing wedge osteotomy (RCWO) on wrist mechanics and loading of the wrist using rigid body spring modeling (RBSM). The model was tested in 29 patients with lunatomalacia, of whom 10 were at stage II, 16 at stage IIIA, two at stage IIIB, and one at stage IV. Radial step cut osteotomy was performed on the radius with an average angle of 9.6° (5° -22°). Preoperative ulnar variance was on average -0.4, and postoperative + 0.3 mm. Computer modeling served to calculate percentile forces on the joints. For the radioscaphoid joint, the increase was 15% and for the scaphocapitate joint 8%, whereas the lunocapitate joint decreased by 23%, 10% was the figure for the radiolunate joint, and 36% for the ulnolunate joint. There occurred a radial shift in the wrist bones, which was larger in the capitate than in the lunate when the load shifted more to the scaphoid.

Tsunoda et al. (1993) measured the change in the biomechanical indices of the wrist in 30 Kienböck patients, 10 with RSO, 8 RCWO, and 12 combined RCWO + RSO osteotomy. RSO was transversal and RCWO and combined osteotomy were wedge-like proximally to the radius metaphysis. Each group had one Lichtman stage IV; others were stages II to III. Radiological parameters were compared to the contralateral side as well as pre- and postoperatively with each other. Preoperatively, compared to the contralateral side radiolunate angle (RLA), RSA and lunate-covering ratio were significantly higher, and the Ståhl index, CHR and carpal ulnar distance ratio were significantly smaller. There was no difference in the SLA, the inclination angle of the radius, and the ulnar variance. Postoperatively, neither RLA nor RSA significantly improved. SLA was significantly higher in RCWO and in combined osteotomy, The Ståhl index did not improve, nor did CHR. The CUDR and the lunate-covering ratio were significantly increased in all osteotomies, so all had a parallel effect that reduced the axial load of the lunate due to as well as improvement of the ulnar translation of the capitate and the increase in the radial loading surface of the lunate.

Kam et al. (2002) investigated in 19 cadaveric wrists the effect of radial closing and opening osteotomies on lunate loading and found that opening osteotomy reduced 26% of lunate "cortical strain" load, while closing osteotomy increased this load by 24%. This difference was significant. The angle of osteotomy ranged from 3° to 15°, but this did not affect the result. The pressure was measured with rosette strain gauge sensors applied to the lunate.

Nakamura et al. (1991) published findings on 27 Kienböck patients who had undergone RCWO 2.7 (2-5) years earlier by what is called the "step-cut" abbreviation. Patient age ranged from 14 to 44 years. The ulnar variance was neutral or positive in 11 and negative in 16 patients. The results were evaluated by the Nakamura score, with a maximum clinical score of 21 points (pain, grip strength, and increment of ROM) and of radiology of 9 points (correction of the lunate, Ståhl index, and CHR). At follow-up, six patients were painfree (22%), others had mild exertion pain. The Nakamura scoring result was excellent in 2, good in 12, and moderate in 13 patients. The results were the best in young patients (14-29 vs. 30-54 years) and in cases where the angle of the radius was changed by 10 to 15 degrees.Extension-flexion improved an average 17° (82° vs. 99°), total deviation of 6°. The prosupination limitation for 12 patients ranged from 10° to 35°, in general to pronation. However, this did not hamper any patients. Grip strength was preoperatively 63% and at follow-up 82% of contralateral with an improvement of at least 5 kg in 19 patients.

The Ståhl index remained unchanged in 12 (44%) and worsened in 14 patients, CHR, respectively, remained unchanged in 17 patients and deteriorated in nine. Lunate sclerosis improved in 12, cystic changes in 10, and segmentation in 3

patients. The increment of the variance was 0.8 mm on average. Neither variance, stage, follow-up time, nor the amount of radial shortening did not affect the results.

Miura et al. (1996) published results from RCWO using a wedge osteotomy and, if necessary, shortened the radius (Figure 8). Patients numbered 26, average age 31.7 (15-58) years. There were 7 women and 19 men, and 19 patients did heavy work. There was no trauma history, and the disease occurred on the dominant side in 19 cases. Lichtman's classification was stage II in 2, stage IIIA in 18, stage IIIB in 5, and stage IV in one; 3 had ulna plus variance, 19 neutral, and 4, minus variance. The monitoring period was 4.8 (0.8-10.5) years. Surgery was performed by the volar route and the osteotomy level was approximately 5 cm from the level of the radial styloid. Osteotomy was fixed with a 4-hole plate. The osteotomy angle was 15 degrees, and in the plus variance at the same time ulnar osteotomy shortening was done.

The pain decreased in all, 18 (58%) were painfree. The Nakamura score was excellent in 8, good in 11, satisfactory in 6, and poor in one patient, and 25 (96%) were satisfied with the result. The active movement of the wrist increased from an average of 83 degrees to 97°, and the grip strength from 62% to 82% of the contralateral.

CHR decreased (0.51 vs. 0.50), as did the Ståhl index (34 vs. 32), the changes being non-significant.Lunate's structure improved in 19 (73%) patients. There were no changes in wrist angular measurements (RSA, SLA, RLA). The lunate-covering ratio increased from 69 to 82, and the inclination of the radius decreased from 27 degrees to 15. The fair and poor results correlated with the preoperative stage and with an increased flexion position of the lunate (RLA 17.7° vs. 5.2° and postoperatively 14° vs. 5.9°). This change did not relate to the scaphoid flexion position, but possibly to the collapse and fragmentation of the volar part of the lunate. Radial closing wedge osteotomy proved to be otherwise effective in the treatment of Kienböck's disease.

Wada et al. (2002) published the results of the same procedure in 13 patients after on average 14 (10-17) years of follow-up (Table 4). The average age of the patients was 37 (18-59) years, six were women, and the right side was confirmed in 11 cases, as well as being the dominant side. Lichtman classification was stage II in two patients, stage IIIA in 8, and stage IIIB in 3. A radial closing wedge osteotomy was performed approximately 5 cm from the level of the radial styloid with a wedge of 15 degrees. Two were resected as trapezoidal due to the minus variance of the ulna. In all patients, pain was reduced compared to preoperative with three being painfree (23%), eight with mild pain in exercise and two in daily activities. All the movements improved significantly with preoperative, flexion / extension being 53° / 59°. Grip strength was preoperatively 63% and at follow-

up 98% of the contralateral. The Lichtman stage was stage II in five, stage IIIB in four, stage IV in four. A total of eight patients showed progression.

The inclination of the radius decreased significantly (28° vs. 15°) as did CHR, (0.51 vs. 0.48) and Ståhl index (33 vs. 27). The carpal ulnar distance ratio (0.30 vs. 0.42) and lunate covering ratio (68 vs. 82) increased significantly, but no change appeared in the variance or wrist angle measurements (RLA, RSA, SLA). The clinical situation improved, although there was progression in radiology. The operation did not correct the flexion deformity of the scaphoid.

Iwasaki et al. (2002) compared the results of RSO and RCWO in 20 patients with stages IIIB to IV disease. Patients numbered 20, and of those, 11 had radial closing wedge osteotomy, 9 RSO. In the RCWO group, 10 patients had stage IIIB and one stage IV, in the RSO group 9 had stage IIIB and one stage IV. In the RCWO group, the ulnar variance was neutral or positive and in the RSO group negative. The wedge osteotomy was 15°. Osteotomies were attached with a DC-plate. The average monitoring period was 2.4 years. In the RCWO group, six patients were painfree, all in the RSO group. DRU joints were asymptomatic. There was no difference between the groups in Nakamura score, all patients being excellent or good. There were no complications. Extension-flexion improved in only RCWO patients significantly, but grip strength improved in both groups. Lunate condition improved in the RCWO group in one and in the RSO group in four patients. In the RCWO group, joint degeneration increased in two cases, and the Ståhl index in this group decreased significantly along with an increase in RSA. In the RSO group no significant difference emerged in the radiological parameters. Both procedures improved the pain and function levels. For stage IV, no conclusions were possible, because of the small size of the material. Probably osteotomy could be considered only in early stages.

Tatebe et al. (2007) published on 31 Lichtman stage-III Kienböck patients with dislocated fracture of the lunate in lateral X-ray image. All were subjected to a step-cut type of RCWO, and at the same time, shortening of the radius in the ulna minus cases. The average patient's age was 35 years. The monitoring period was a mean 5.2 (1.5-12.4) years. At follow-up, 8 were painless (26%), 15 had mild pain. 7 moderate and one had severe pain. MWS averaged 70. Average extension-flexion was 84° and grip strength 30 kg. One patient later had three procedures. The fracture united in 16 patients. They concluded that dislocated fracture associated with Kienböck's disease healed in half these patients. On the other hand, the results were good clinically, even though no union was evident.

Shin et al. (2017) compared the results between RCWO (11 patients with Lichtman stage IIIB/IV, group A) and RSO (14 patients with Lichtman stage IIIA, group B). The monitoring period was a mean 7 (4-14.5) years in group A and 7 (4-12) years in group B. RCWO was done in neutral or positive ulnar variances.

The end results did not differ clinically. Pain VAS was in A 1.2 (0-3) and 1.1 (0-5) in B. DASH scores were respectively 10.6 (0-28.3) and 14.2 (0-38.3). Extension-flexion (64% vs. 62%) and grip strength of the healthy side (46% vs. 49%) did not show significant differences. Ståhl index was in group A 34 and in group B 50, but the figures were the same already preoperatively. The author's conclusion was, that RCWO yielded excellent radiological and functional outcomes in advanced stages of Kienböck's disease and the results were comparable to those of RSO in Lichtman stage IIIA.

2.11.5.3. Summary of publications on osteotomy of the radius

Pain relief was often observed in patients who went through the osteotomy, and in the series presented in Table 4 an average 46 (19-66) % of patients were painfree. Some articles, also noted the ability to work, and most of the patients were able to perform their jobs. The ROM most often improved, as did grip strength. Wrist collapse was not usually repaired, but the aggravation was often prevented, or the change remained unchanged. Lunate bone structure improved in some publications, but at follow-up, the Ståhl index and disease stage did not usually improve. The incidence of arthrosis was rarely estimated, but when it was, it ranged from 0% to 73%. Problems with the radioulnar joint are often mentioned in the shortening osteotomy. In these articles, DRU joint arthrosis was mentioned in eight of nine articles, ranging from 0% to 41%, with an average of 15%. Indications varied, and in some articles, osteotomy was also considered possible in stage IIIB and in ulna neutral variance.

2.11.5.4. Ulnar lengthening osteotomy, ULO

The lengthening of the ulna in the minus variance increases ulnocarpal and reduces lunoradial pressure as previously shown in experimental biomechanical studies. Persson (1945) published 19 patients' data, in which 14 patients had an ulnar lengthening and three radial shortening osteotomies. The technique used for radius osteotomy followed the limitation of prosupination and was abandoned. The ulnar lengthening was compared with the conservatively treated control data collected elsewhere and showed that wrist movement was better after osteotomy. Persson (1950) published on a new series from 1945 to 1949, which had 14 ulnar lengthening osteotomies. At follow-up, the symptoms were relieved, and with one exception, the patients were able to handle their jobs.

The results were compared to those of Ståhl in 1947, showing that wrist movement was better than among those only immobilized. The lunate was compressed more in three, and bone union was followed in six of nine patients (67%) for two years but was followed in only 30% in Ståhl's data. Arthrosis was found in four, in Ståhl's 105 cases found in 10. Aging had a negative impact on

outcome. The author stated that the ulnar lengthening osteotomy was considerably superior to immobilization and noted that the treatment was directed towards the etiology of the disease, that is, the minus variance and the trauma etiology. The monitoring time went unreported.

Armistead et al. (1982) published a Mayo Clinic study in which ulnar lengthening was performed in 20 patients, 5 women and 15 men, average age 28 (18-50) years. The ulnar variance was -3.1 mm on average, and four had a neutral variance. A transverse osteotomy was performed on ulna diaphysis, and the fixation took place with a 4-hole plate; distraction was used, in addition to an intercalary bicortical bone-block extracted from the iliac crista. Immobilization was with a splint and later a long plaster cast for 4 to 6 weeks. The plate was removed after 12 to 15 months. Three non-unions developed, healing after reoperation. The monitoring period was on average 3 years. At follow-up, 7 patients were asymptomatic (35%), 11 had mild occasional symptoms, and in 2 the result was unsatisfactory; 17 patients were satisfied, and 18 returned to their former jobs. ROM improved except for ulnar deviation (extension 81% to 84%, flexion 62% to 70%, radial deviation 59% to 86%, but ulnar deviation 62% to 53%). Grip strength improved from 53% to 70%. One patient had a limitation in pronation. Radiologically, the ulnar variance was neutral or positive, with a single -2 mm. Of the 20 patients, lunate sclerosis had diminished in 6, with one increased, and 13 patient situations were unchanged. Preoperatively, ten patients had a fracture of the anterior pool of lunate, of which only one healed. A fracture of the dorsal pool occurred in four, seven lunates had a sagittal and one a comminuted fracture. The proximal pool had collapsed in nine cases. Of these, seven united, and this union was verified by CT. CHR was done preoperatively for 11 patients, (ranging 0.50-0.46), and in one patient collapse increased. The authors considered the results as similar as Persson`s and promising. Nonunion can be avoided by a careful surgical technique. A plate removal was done under local anesthesia as an outpatient.

Sundberg and Linscheid (1984) published a new Mayo Clinic study on 22 ulnar lengthening osteotomies, and they also compared their results with those previously published. The age of the patients was 22.8 (14-42) years. The average follow-up time was 3 years. The disease was in 13 patients in the right hand and on the dominant side in 11, with 18 being men. Eight patients did heavy work and eight light work. The duration of the symptoms was a mean 18 months. Everyone had pain, four difficult pain, and there were 12 cases of trauma. Extension was 66%, flexion 55%, radial deviation 63%, and ulnar deviation 64% of the contralateral with grip strength of 52%. Sclerosis was present in all lunates, cysts in 8, and a fracture in 13. A trispiral CT was made for 18 patients. One had mild degeneration in the radiolunar joint and one a scapholunar dissociation. Twenty patients had a minus variance of the ulna, on average -2.4 mm, and two had a neutral variance.

The surgical technique was the same as in the previous publication and mean ulnar variance after surgery was +0.9 mm. Immobilization took 6 weeks. 19 of these 22 patients attended the follow-up, 14 were completely painfree, 4 were seldom in pain, and one had a silicone arthroplasty when pain continued; 18 had returned to their former jobs. All osteotomies united. ROM somewhat improved: extension was 77%, flexion 69%, radial deviation 72%, and ulnar deviation 64% of the contralateral. Prosupination had no restriction, and grip strength was 72% of the contralateral. One patient fell 4.5 months after surgery: the lunate broke, and the wrist collapsed.

One complication was damage to the sensor branch of the radial nerve. In CT, of 13, 5 fractures had consolidated, 6 showed no change. In eight cases, sclerosis decreased and in three increased. Seven lunates fragmented and collapsed with CHR deterioration 0.01-0.04. Compared to the previous study, changes were minimal. Fracture healing was found in this material in 54% and in the previous study in 36% of the fractures.

Schattenkerk et al. (1987) compared the results of RSO and ULO for 35 patients. Of these, 20 were done with RSO, and 15 were ulnar lengthening procedures. The RSO group`s primary staging was worse. The RSO monitoring period was on average 4 years and that of ULO 6 years. The article does not show how the groups were formed. In the RSO group, 10 of 20 were painfree, and in the other group of 15, 9. In the RSO group, a nonunion existed in one, the other group in three. In both groups, the effect on the symptoms was favorable, and the objective result were almost the same. The RSO group had fewer complications and the union-time in RSO was shorter.

Quenzer and Linscheid published in 1993 Mayo Clinic long-term questionnaire results on 64 patients, with 59 responding, having an average of 7.8 (1 to 14.3) years of follow-up. In 60 patients, an average follow-up was 24 months and in 47 over 12 months. Patient satisfaction was high, pain relief was 86%, satisfaction with surgery 90%, and rate of return to work 70%. Complications occurred in 22% of patients: nine had a delayed union or nonunion (14%) and five developed an ulnar impingement (8%). The plate was removed from 28 patients (44%), and 3 (5%) were re-operated for non-union. After technically successful surgery, 11% had additional surgery for wrist pain, ao. partial fusions, silicone implants, and other salvage procedures, excluding wrist fusion.

Of these 64, 39 patients had a follow-up X-ray examination at least one year after surgery. The ulnar variance was on average +1.4 mm. Lunate density was unchanged or improved in 88%, the lunate cysts were smaller or unchanged in 90%. Progressive lunate collapse occurred in 12% and new fragmentation in 10% of these patients. New fragment extrusion occurred in five (12%). Progression of the disease to a worse stage was neither noted nor evaluated by X-ray images and CT,

and in only three patients did CHR deteriorate (10%). The long-term effect of the procedure was obvious, and the progression of the disease was not significant. In the ulna minus variance, the authors recommended a "to level the joint" treatment.

Trail et al. (1996) published data in which 16 patients with Kienböck's disease were subjected to 16 ULOs and 4 RSOs (Table 4). The monitoring period was 11.6 (6-16) years. The age of the patients was a mean 27 (14-43) years. The ulnar lengthening was an average of 4 mm and the radial shortening 2 mm. There were one nonunion and two delayed unions in ULO. The fixation was a plate, and one plate had to be removed after RSO due to tendon irritation. Fourteen patients were later subjected to additional measures: one lunate screw fixation, one STT arthrodesis, and one dorsal ganglion removal. Eleven plates were removed. Pain was relieved in all, and four were completely painfree. Resuming full-time work was possible for 75% without any problems. ROM improved significantly, extension-flexion from 79° to 112°. Grip strength improved significantly, from 55% to 94% of the contralateral. The Lichtman stage was preoperatively in X-rays: stage I / 2, stage II / 10, and stage III / 8. At follow-up in a CT study, the stage was: stage II / 8, stage III / 10, and stage IV / 2. Lunate density decreased from the primary 16 to 6 at follow-up, cysts were still evident in CT in 19 patients, and lunate flattening persisted. Lunate fractures existed in the initial X-ray image in 8 patients and in CT in 14 patients. In the follow-up-CT study, there still was apparent a fracture in 10, but in 7 it had healed. Into the lunate fossa had come new bone formation in 13 patients; 13 patients had arthritic changes, especially in the scaphoradial joint. The clinical outcome was still good at 11 years of follow-up, and no collapse of the lunate or wrist had occurred, but changes in the lunate were not corrected in most patients. RSO appeared to be better because it demonstrated fewer bone-union problems.

Ducarmois and Van Innis (1997) presented nine patients with a follow-up time of 24 years. ULO had a good effect on pain and strength, but ROM deteriorated. Lunate morphology was not repaired. Long consolidation time and high pseudoarthrosis frequency were disadvantages, as was ulnar abutment in too-extensive lengthening. The measure was recommended mainly for young patients.

Kawoosa et al. (2007) published on 12 patients in whom ULO was done by a distraction method. This was to avoid the problems associated with osteotomy. The distractor was held for 7.3 weeks, and the planned lengthening was achieved except for one case where the planned extension was lost 1 mm without any additional adversity. Two pin infections were treated with antibiotics. The data consisted of six stage-IIIA- and six IIIB patients. The monitoring time was 2.4 (0.8-5) years, and the result of the Nakamura score was one excellent, ten good, and one moderate. Extension improved 18° and flexion 9°, and grip strength was 70% of the contralateral. CHR improved slightly, and carpal collapse did not worsen.

The results of the ulnar lengthening osteotomy correspond to RSO results. However, its use has remained minor, apparently mainly due to post-osteotomy healing problems of the ulna.

2.11.5.5. Capitate osteotomy, CO

Osteotomy of the capitate, the so-called Graner procedure, has been used in Kienböck's disease, especially in central Europe. In surgery, the lunate is either retained and the intercarpal joints are fused except the STT joint (Graner I) or the lunate is removed. In this case, the capitate is osteotomized from the distal and mid-third line, transposed into the position of the lunate, and the bone defect is filled with free bone transplants and the intercarpal joints are fused, with the exception of STT (Graner II).

Plaas (1973) published data on nine patients (G II), of whom only three were painfree at 3 (1-5) years of follow-up. Everyone was at work, two had mild arthrosis, and all had clear limitation of ROM, extension was 21° (41%) and flexion 17° (34%).

Bartelmann et al. (1998) published on 17 patients who had GII data and were at stage IIIA and B from 1992 to 1995. Four patients had pain, 13 were painfree or had pain only under more severe strain. Extension-flexion was 55° and grip strength 67%. Capitate necrosis was found in four, pseudo-arthrosis in two, and radiocarpal osteoarthritis in five patients. Due to a poor radiological result, the procedure was not recommended for use.

Takase and Imakiire (2001) published on 15 stage-IIIB to IV patients who had Graner II with a follow-up of 6.6 (5-12) years. None had pain at rest, two had pain when using the hand. Extension averaged 36° and flexion 40°, and grip strength 83.7% of the contralateral. All had radiocarpal joint arthrosis. The result was considered good.

Facca et al. (2013) published four-patient data, followed up for 25 years. One had a radiocarpal arthrodesis. VAS pain was 3.3 and DASH on average 36.6. ROM was about half that of the contralateral, and grip strength 81 %. They did not recommend the Graner II procedure for Kienböck's disease.

To avoid healing problems and capitate necrosis, surgery has been modified by making a callotasis lengthening of the capitate (Hierner and Wilhelm 2010). Ten IIIA patients' follow-up averaged 5 years, IIIB was considered a contraindication, as was local arthrosis. All were manual workers, and eight were able to continue in their former jobs. DASH was 34.5 (29-44). Extension-flexion decreased from 66° to 56°, and grip strength improved from 15.4 kg to 21.8 kg. One patient had a wrist fusion due to a pseudo-arthrosis, and nine had palmar malalignment of the proximal capitate part, which can cause an articulation change over time. In the MRI study, the blood supply of the capitate was maintained in all. This method avoids the need for a free-bone transplant.

2.11.5.6. Capitate shortening osteotomy, CSO

Capitate shortening osteotomy (CSO) has allowed surgeons to reduce pressure on the lunate, particularly in ulna-neutral and -plus variance, wherein RSO is generally not recommended due to potential ulnar abutment and potential incongruence of the distal radioulnar joint. The first results by this method were published by Almquist (1993). He also combined capitohamate fusion to this method.

In experimental cadaver work, Werber et al. (2012) found that a shortening of the capitate of about 2 mm reduced the load on the lunate by 49%, judged by a 9.8 N load on the wrist and 56% at a 19.6 N load.

Gay et al. (2009) published results from 11 CSO patients after a shortening of the capitate for 2 mm made to the border of the middle and distal third of the capitate. Five patients had stage II and six IIIA, and all had a neutral variance. During 5.6 years of follow-up, two patients (18%) underwent revision surgery for continuing pain after 6 and 9 months. VAS was on average 1.7 (0-7). According to the Nakamura score, the result was good in six, moderate in one, and poor in three. Nine patients returned to their work after an average of 6 weeks. Extension-flexion was 66° and grip strength 72% of the contralateral. Stage worsened for two IIIA ad IIIB and improved for three patients. No non-unions resulted, and neither osteonecrosis of the capitate. Revision surgery was performed in two patients.

Afshar (2010) investigated, by MRI, lunate vascularization after CSO in nine patients, all of whom had a neutral or plus variance staging II-IIIA. The average tracking was one year. Everyone developed partial revascularization on average within 4.7 (3-7) months.

Waitayawinyu et al. (2008) incorporated CSO to the lunate revascularization using metacarpal III basal bone transplantation. The follow-up time of 14 patients averaged 3.4 (2.1-5.4) years. Six had stage II and eight stage IIIA disease and ulna plus variance averaging 1.9 mm. The capitate was shortened by 2 mm, and part was also subjected to a hamate shortening osteotomy, especially when the hamate and lunate were joined. All osteotomies healed, either by screw fixation in a mean 48 days or by Kirschner wires in 65 days. ROM slightly deteriorated, extension-flexion was 110° (78%) and grip strength improved from 58% to 78%. The result was better for these items in stage-II patients. No arthrosis appeared, and the height index of the wrist remained unchanged, with 13 patients returning to their former work and 12 to former activities.

Hegazy et al. (2018) reviewed 22 patients, all having ulnar neutral variance, who were treated by distal capitate shortening and arthrodesis to the third metacarpal base. Lichtman stages were II (12 patients) and IIIA (10 patients). Follow-up was 2.5 (2-3) years. Both clinical and radiological results were significantly better in Lichtman stage II patients. The authors did not recommend this operation for stage IIIA patients.

2.11.6. Lunate revascularization procedures

Clinical, radiological, and histological change in the lunate in Kienböck's disease matches avascular osteonecrosis. Particularly at the early stages of the disease, when the shape of the lunate is still preserved and there is no cartilage damage in the joint, the idea arises that progression of the disease could be prevented by improving the blood circulation of the bone. Lunate revascularization has been accomplished by a variety of methods including implanting a blood vessel pedicle into the bone, possibly in combination with a bone transplant, or by transferring the vascularized pisiforme bone either as such or as decorticated inside the lunate. Generally, also grafts of the distal radius have been used, and also as a graft with the pronator quadratus muscle or with a blood-vessel pedicle. A vascular iliac crista graft has also served equally well as transposition of the II or III metacarpal proximal portion. Revascularization can be combined with lunate decompression (RSO, STT-arthrodesis / temporal STT fixation or wrist distraction by external fixator) (Kakar and Shin 2010, Kakar et al. 2011).

Tamai et al. (1993) published on 51 Kienböck patients who had been treated by implantation of the II or III metacarpal artery with its concomitant veins into the lunate. In Lichtman stage I to II (I / one, II / five patients), only a blood vessel was carried out through the lunate and fixed to the wrist volar capsule using the technique descriped by Hori et al. (1979). In stage-III patients (39) and in mild stage-IV (6), the necrotic area of the lunate was evacuated, grafted with cancellous bone, and the vessel implanted through the transplanted bone. In 8 cases, a wrist distractor was also used for 7 to 8 weeks, and 18 patients also received STT arthrodesis, and in 2 a temporary K-wire fixation of the STT joint was used. A minus variance of the ulna existed in only 10 (20%), neutral variance in 34 (66%), and plus variance in 7 (14%). The monitoring period was 5.9 (2-15) years. Pain was relieved or reduced in 50 of the 51 patients (98%). On the grading scale of Lichtman Evans, the result was good in 34, moderate in 12, poor in 4, and very poor in one patient.ROM improved from 67° to 82°, except in the STT fusions, and grip strength improved from 17.7 kg to 30.7 kg. The carpal height remained unchanged in 61%, decreased in 23%, and improved in 17% of the patients. Sclerosis and cysts disappeared in 72%, osteoarthrosis still existed in 19 %, and lunate fragmentation increased in 10 % of the patients. In summary, the measure was useful in Stages I to II patients, in Stage III it should be combined with a biomechanical procedure or STT arthrodesis, and the procedure was unsuitable for treatment of Stage IV.

Gabl et al. (2002) published on 18 Kienböck patients in whom the necrotic area of the lunate was evacuated and filled with a vascularized cortico-cancellous bone graft from the crista iliaca, and the wrist was stabilized by external fixation. All patients had stage-III disease. During the five-year follow-up, results were good. The structure of the fractured lunate was restored, collapse of the wrist was

prevented, and the clinical situation became even better. The graft was incorporated in 16 cases, resorbing in two.

Arora et al. (2008) published the same material after 12.7 (10-14) years of follow-up (Table 5). Lichtman stage IIIA was that of 15 patients, and IIIB of 3. In two patients, the graft resorbed, and the result was poor: their VAS was 8, DASH 57, and the disease progressed to stage IV. Neither wanted any action taken. In the other 16 patients, VAS was 7 (0-19) on the scale of 0-100 whereas it was 64 before the measurement. DASH score was 8.4 (0-42). With Green and O'Brien scoring, the result was excellent in 8, good in 5, and moderate in 3 patients. Extension-flexion was 73% on average and grip strength 76%, both improving significantly. Two patients had to change their work *due* to illness. There was no significant difference between CHR (0.54) and Ståhl index (40) in preoperative comparisons, nor in RSA. Of these 16 patients, 9 underwent post-operative MRI scanning, and revascularization of the lunate was found on average at 19 (4-32) months. The situation had remained stable compared to the 5-year monitoring. Osteointegration of the graft was noted in 16 (89%) patients. The authors considered it important to use an external fixation in the healing phase, because the acute phase of revascularization is associated with increased osteoclast activity, which weakens the bone (Aspenberg et al. 1994). The role of cortical bone in the graft may also be significant for stability. The height of the wrist remained, without any wrist instability. This study made no mention of ulnar variance.

Lunate vascularization has also utilized a decorticated pisiform bone which is inserted into the lunate after the removal of the necrotic region, occasionally also accompanied by a cancellous bone transfer. The blood flow of the pisiform is maintained by the dorsal branch of the ulnar artery. The data of Bochud and Büchler (1994) comprised 30 patients (32 wrists) with an "early Stage III" illness, one of whom was unavailable, one had undergone arthrodesis and one, PRC. In 22 patients (28 wrists), a debridement, cancellous bone transfer, and correction of the shape of the lunate were performed. Vascularization was performed as a vascular implantation according to Hori et al. (1979), and six were made with a pisiform transfer. In 19 cases, an external fixation allowed reforming of the lunate. In 11 cases, RSO was performed when the ulna minus variance exceeded 2.5 mm. The follow-up time was 6.7 (2.5-9.3) years. At follow-up, a trispiral tomography and magnetic resonance imaging were also used. Twelve patients (46%) were completely painfree, 11 had difficulty during heavy work, and one with daily activities. Resting pain did not exist. Pain score was preoperatively 2.5 and at follow-up 0.8 (scoring 0-5). Everyone returned to their previous jobs. ROM did not improve significantly. Grip strength was 80% of the contralateral (38 kg, improving by 47.5%). The form of the lunate did not survive, being correct in only 41%; at follow-up, 15% had collapsed. Non-union improved in 8 of 10, but the lunate`s

proximal deformation “plaque depression” was repairable in only 4 of 25; 42% of the lunates were wholly or mostly vital, 15% still necrotic, and 37% of the lunates were normal in shape, structure, and vitality. In 23%, the situation had remained stable. There were 12 patients with arthrosis, according to preoperative tomography of 10, 2 with progression. Arthrosis did not correlate with pain. When the lunate was vital, deformation was slighter, wrist height was maintained better, and the progression of arthrosis was slower.

Wünster-Hoffman and Homann (1997) published the results of vascularization by an equivalent pisiform technique with 18 patients after 2.5 years of follow-up. The disease level was stage II, and eight also had RSO due to ulna minus variance. The monitoring time was 2.5 (2-5) years. Six months after surgery, the graft was incorporating, and signal intensity increased in the MRI study, with the exception of two patients. In 17 patients, pain was relieved, and ROM improved in 14 patients at a mean 30°.

Daecke et al. (2005) published on 29 patients with stages II to III, all having core revascularization with a decorticated pisiform. One had later a wrist arthrodesis, and five dropped out of monitoring. The follow-up time of 23 patients was 12.5 (5.1-22.2) years (Table 5). Stage II applied to 13, stage IIIA to 6 patients, and stage IIIB to one patient; 11 patients also had RSO, one of them in advance. An ulna minus variance existed in 14 patients. The aftercare was first a volar splint and later, a plaster of cast for 4 weeks. At follow-up, 8 patients were completely painfree, 12 had pain with heavy manual strain, and three with daily activities. VAS (range 0 to 10) was 2.2. Twelve patients experienced no limitation in hand use. DASH was on average 15.3 (0-63) and significantly higher in stages II to IIIA compared with IIIB to IV. The Cooney score was 82.4. ROM improved significantly, 78 % of the contralateral and grip strength 84 % of the contralateral. Lichtman stage improved in three and worsened in six patients, three of them also had RSO. RSA did not significantly change (50° to 54°), nor did Ståhl index (0.38 to 0.37) nor CHR (0.52 to 0.53). RSO patients did not differ from others. Eight patients had mild arthrotic changes. In 20 patients with grafts, osteointegration was evident. In three patients, the lunate had fragmented, and in 11 of 22 there occurred a flattening in the middle part of the lunate; 16 lunates had sclerosis, and 6 had normal trabecular structure. A total of 6 of the 20 had disease progression. The authors stated that the results were consistent with Koh et al. (2003) RSO results, although Koh`s patients had more arthrosis. Patient satisfaction was high, motion and function improved, and progression of the disease and the onset of arthrosis was prevented in 14 of 22 patients, so the measure was effective.

Mathoulin and Wahegaonkar (2009) presented 22 patients whose stage ranged from II to “late” III (Büchler’s rating). To the lunate was transferred a vascularized graft from the volar radius, and 17 patients had in addition RSO (minus variance)

and the remaining a wedge osteotomy. The monitoring time was 6 (5-10.3) years;18 patients were painfree, and movement and strength improved. Two patients were still as painful as preoperatively.

Elhassan and Shin (2009) presented a technique in which the lunate was vascularized by the 4th and 5th extensor compartmental artery (4 + 5 ECAs), whereby a vascularized bone graft was taken from the dorsal surface of the radius. The indication was a neutral or plus variance of the ulna, and vascularization could be a useful additional action to RSO. Stage IIIB has been regarded as a contraindication, but more important is the situation of the lunate`s articular cartilage. Considered a contraindication was stage IV and a fracture of the lunate in which the fragment was displaced or dislocated. Contraindications are also a fracture of the lunate`s cartilage and previous surgery in the dorsal area of the wrist if the circulation is damaged. Lunate collapse can be corrected in the procedure. Postoperatively, lunate unloading is important, and it is achieved by either an external fixator or a temporary K-wire fixation of a midcarpal joint, usually the scaphocapitate joint. This immobilization lasts for 6 weeks, and the pins are recommended for 3 months.

Moran et al. (2005) published the results of vascularization with 4 + 5 ECA in 26 patients. Of these, 12 were at stage II, 10 were at stage IIIA, and 4 were at stage IIIB; 10 had minus variance, and 19 had a lunate fracture. The average monitoring time was 2.6 (1-6.1) years. Aftercare was in 12 patients a postoperative temporary midcarpal joint fixation and in 8 patients an external wrist fixator. In 24 patients, pain was relieved. By Lichtman score, the result for 22 patients was satisfactory, but for 4 was poor due to pain, 2 of these being subjected to a wrist fusion. Mayo wrist score of 24 patients averaged 77 (35-100). There was no difference between stage II vs. IIIA-B, nor between temporary fixation or pinning group. ROM improved from 68% to 71% and grip strength significantly, from 50% to 89% of the contralateral side. In 20 patients, lunatomalacia or wrist collapse did not deteriorate, but in six patients the stage worsened. Of 26 patients, 17 were subjected to an MRI study for an average of 20 months after the procedure, and 12 of these had a revascularization. Vascularization found in the MRI significantly improved the score. Vascularization was considered to continue to play a role in the treatment of Kienböck's disease.

Fujiwara et al. (2013) published on 18 patients, of whom 10 were at stage IIIA and 8 at IIIB. (Table 5). Revascularization was performed from MCIII basis (9 patients), MC II basis (2), II / III ICSRA (intercompartmental supraretinacular artery) (4) and I / II ICSRA (3). Stage IIIB patients also had RSO (5 patients) or CSO (2). The monitoring was 12.2 (10-15.5) years. With the modified Mayo wrist scoring, the result was excellent in 8, good in 7, and moderate in 3. For two, stage IIIA proceeded to IIIB. ROM improved significantly, as did CHR and Ståhl index,

the latter in Stage IIIB. In the MRI study, revascularization of the lunate occurred in 15 of the 18 patients (83%).

Havulinna et al. (2016) published a Kienböck wrist in which the coronal lunate fracture was treated successfully by the 4. ECA vascularized bone graft excised from the radius.

2.11.6.1. Vascularized interposition arthroplasties and reconstructions

The pisiform bone has served as a vascular graft vascularized by the dorsal branch of the ulnar artery to replace the resected lunate with the technique presented by Saffar and Gentaz in 1982. Saffar published his results (2010) involving 51 patients with stage IIIA or IIIB disease, including stage IV. Seven patients were also given RSO, and 12 had STT or SC arthrodesis. The monitoring period was 15 years at most. The complications were two infections and one CRPS. Pain diminished consistently.One patient was later subjected to PRC. Extension-flexion improved 35° and grip strength about 10%.

Gong et al. (2006) published on 41 Kienböck patients with 13 patients in stage IIIB and 28 in stage IV. Arthrodesis was performed in stage IV if there was severe arthrosis (joint space obliterated) in the radiocarpal joint. The removed lunate was replaced by a bone graft taken from the radius transferred along with the pronator quadratus, whereby the vascularization came via the interosseus anterior artery. The bone graft was surrounded by the muscle. Aftercare was a wrist distractor for 4 to 6 weeks. The monitoring period was 6.1 (3-22) years. At follow-up, 20 patients (48%) were completely painfree, 15 had mild, and 6 patients had moderate pain. Everyone was able to return to their work and activities. Extension-flexion improved from 85° to 100°. The collapse of the wrist increased slightly, CHR from 0.52 to 0.48: this change was not significant. Arthrosis progressed in stage-IV patients in three, and in stage-IIIB patients two developed mild arthrosis. No graft resorption occurred. The authors considered this result of a short follow-up as good.

In advanced Kienböck`s disease, there have also been developed reconstructions replacing the lunate. Vilkki (2007) published on experimental modeling and one patient's case report. This stage-IIIB lunate was replaced by an ipsilateral vascular MTP II joint graft, called a neo-lunate, which corresponded well with the shape and size of the original lunate.

Bürger et al. (2014) published 16 patient's data, in which the damaged proximal part of the lunate was replaced by a vascularized bone graft from the medial femoral trochlea-source (MFT flap). The osteochondral transplant used matched well to the form of the lunate. Seven patients were at stage II in which the lunate was radially compressed, eight at IIIA, and one at IIIB. The average age was 35 (19-51) years. Osteosynthesis was done with screws, Kirschner's pins, or a mini plate.

The monitoring was 1 year. In CT, a bony union was found in 15 patients at 3 to 4 months. Of these, 12 were painfree, and 3 were partially painfree; one was subjected to a wrist arthrodesis due to continued pain. Lichtman stage improved in four and worsened in two patients with increasing wrist collapse. The Ståhl index did not change. There was also no change in ROM, and grip strength was 85% of the contralateral. The initial result was promising, and long-term good results were expected.

2.11.6.2. Other measures aimed at improving vascularity of the lunate

Schultz et al. (1998) presented results by radius and ulna metaphyseal core decompression for ten patients, two in Lichtman stage II and eight in stage III (Table 5). The average follow-up time was 10.8 years. Pain was relieved in nine patients, one developed an SL-instability and arthrosis, and he was symptomatic. Everyone was able to work. Extension- flexion was 74% and grip strength 81% of the contralateral. Ståhl index (39 vs. 36) and the lunate-capitate height index (0.38 vs. 0.37) did not significantly differ. The result correlated with the results of osteotomy, and no complications were observable. The idea of the operation was based on the theory, that the curettage of the distal metaphyseal area would stimulate blood circulation of the wrist area like it happens in fracture healing.

Illarramendi et al. (2001) presented the results by same technique for 22 patients (Table 5). Two had Lichtman stage I, eight stage II and 12 stage IIIA. Initially five cases were excluded for different reasons. The average follow-up time was 10 (6-16) years. There were no complications. 16 patients were painless and 4 had mild pain. Two patients had more pain and one of them arthritic changes. Extension-flexion was 77% and grip strength 75% of the healthy side. Lichtman stage deteriorated in 3 and improved in 2 patients. The height of the lunate was unchanged. Five patients had preoperative MRI and at follow-up four of them became better, one wrist being quite normal.

De Carli et al. (2017) published on 15 stage-IIIA patients with radius core decompression (Table 5). The monitoring was 13 (10-18) years. Preoperative VAS score (0-10) was 7 (6-10) and at follow-up 1.2 (0-6). MWS was preoperatively poor in all, at follow-up only in one. In eight, it was good, and in six excellent. There were no complications.

Extension-flexion was 77%, and the dominance-corrected grip strength 80% of the contralateral. CHR fell in three, in others remained unchanged. In two wrists, the stage fell, one to IIIB, and the second to IV. This patient had revision to PRC. In their biomechanical study, Sherman et al. (2008) found that after a core decompression, the stiffness of the distal antebrachium was significantly reduced. However, the lunate's load did not change, so the effect on the lunate is likely to be vascularly based.

Mehrpour et al. (2011) published the results of the lunate`s core decompression in 20 patients. Their idea was similar to that previously applied to the treatment of hip avascular necrosis. The Lichtman stage was in ten patients I, stage II in six, IIIA in three, and one IIIB in one. The lunate drilling was made from a small dorsal opening. The wrist was splinted for 6 weeks. The average follow-up time was 5 years. There was no change in pain in two patients, and RSO was done later. VAS (0-100 scale) improved from 88 to 14 and DASH from 84 to 14. These changes were significant, as was the improvement in motion; extension-flexion improved from 48° to 115°. CHR remained the same. No X-ray documentation was available.

Lunatomalacia has also been treated with avascular bone transplants. Zelouf and Ruby (1996) published 17-patient data in which Lichtman stage was in one I, in eight II, in 6 IIIA, and in two IIIB. The monitoring was 4.7 (2-8) years. The lunate was explored through a dorsal approach, the necrotic bone was removed, and the defect was filled with a bone graft from the anterior iliac crista or from the same side radius. External fixation was used for an average of 9.8 weeks. Six patients were painfree, eight had intermittent mild pain, plus one with moderate and two with difficult pain; 14 patients were able to work, two were limited, and one was unable to work. MWS was on average 79. Extension-flexion was 113° and grip strength 81% of the contralateral. In three patients, the result was poor, one was subjected to PRC and one to an arthrodesis; the third did not accept any additional procedures. In 12 patients, the lunate was radiologically unchanged, and 3 were diagnosed with lunate collapse and disease progression. Ten patients were subjected to MRI for an average of 23 months of the procedure, and in half of them the lunate signal intensity was better, though not normal. Based on these results, the authors recommended this procedure for stage I-II disease.

2.11.7. Intercarpal arthrodeses

Some types of intercarpal arthrodesis have been used especially in advanced Kienböck`s cases, with the aim of reducing compression on the lunate and preventing the wrist from collapsing. The most commonly used is scaphotrapetziotrapzoidale (STT) arthrodesis. According by Horii et al. (1990), it however reduces the compression load of the lunate by only 5%, whereas ULO or RSO reduce it by 45% (Figure 7). Scaphocapitate arthrodesis has a similar effect, while capitohamate arthrodesis does not reduce the lunate load. Individual articles are also available on radiolunate arthrodesis. Temporary fixation of the STT joint has been used in certain situations, eg. in juvenile Kienböck`s disease.

Table 5. Long-term results (mean ≥ 10 years follow-up) of different treatment modalities in Kienböck's disease. Revascularization, core decompression, partial arthrodesis and proximal row carpectomy

Authors	Year	N patient/ wrists	Treatment	Initial Lichtman stage I / II / III/IIIA / IIIB / IV	Follow-up time, years mean (min-max)	Pain VAS or presented numbers	Grip strength % of contralat	ROM[1] ext/flex (°) or % of contralat.	DASH[2] mean (min-max)	MWS[3] mean (min-max)	Progression (in Lichtman stage), %.	Arthrosis presence %
Daecke et al.	2005	23	Vasc.pisif. 12, vasc. pisif+RSO 11	0 / 13 /- / 6 / 1 / 0	12 (5-22)	VAS 2.2. no pain 8, in heavy strain 12, 3 in daily activitis	84	59°/54° 81%/76%	15.3 (0-63)	82	30 (15% better)	32
Arora et al.	2008	16	FVIBG	0 / 0 / - / 15 / 3 / 0	12 (10-14)	VAS 0.7. (0-1.9)	76	73%	8.4 (0-42)	-	11	11
Fujiwara et al.	2013	18	VBG mc II-III 11, radius 7 +RSO 5, CSO 2	0 / 0 / - / 10 / 8 / 0	12 (10-15)	-	87	83%/79%	-	excellent 8, good 7, fair 3	11	0
Schulz et al.	1998	10	MCD	0 / 2 / 8 / - / - / 0	10.8	no pain 6, mild 3, severe 1	81	74%	-	-	20	10
Illarramendi et al.	2001	22	MCD	2 / 8 / - / 12 / 0 / 0	10 (6-16)	no pain 16, mild 4, moderate 1, severe 1	75	59°/57° 77%	-	-	14 (9% better)	4
De Carli et al.	2017	15	RCD	0 / 0 / - /15 / 0 / 0	13 (10-18)	VAS 1.2. no pain 7, mild 6	80	77%	-	Excellent 6, good 8, poor 1	13	6
Van den Dungen et al.	2006	11	STT-fusion	0 / 1 / 10 / - / - / 0	14 (6-18)	no pain 2, in strain 6, barometric 8, at rest 1.	60	74°	17 (2-59)	-	64	55
Croog and Stern	2008	18	PRC	0 / 0 / - / 5 / 12 / 1	10 (4-17)	no pain 7, mild 9, moderate 2	87	56°/49° 78%	12 (0-50)	84 (60-100)	-	87
Lumsden et al.	2008	13	PRC	0 / 0 / 13 / - / - / 0	15 (11-20)	no pain 5. mild 6, in strain 2	92	73%	-	-	-	82

[1]Range of motion; [2]Disabilities of the Arm, Shoulder and Hand; [3]Mayo wrist score.Abbreviations: Vasc. pisif. = vascular pisiform transfer, RSO = radial shortening osteotomy, FVIBG = free vascular iliac bone graft, VBG = vascular bone graft, mc = metacarpal, CSO = capitate shortening osteotomy, MCD = metaphyseal core decompression, RCD = radial metaphyseal core decompression, PRC = proximal row carpectomy.

2.11.7.1. STT arthrodesis

In addition to Kienböck's disease, STT arthrodesis has been used in many other indications such as STT arthrosis and scapholunar instability. A prerequisite for the measure is that the radiocarpal joint is intact.

Watson et al. (1996) published the largest series on STT arthrodesis for Kienböck's disease, consisting of 28 patients of whom 9 were at Lichtman stage II and 19 stage III. The monitoring time was 4.2 (1.1-9.5) years. Subsequently, nine lunates had to be removed and seven silicone implants were placed, one lunate was partially removed, and two PRCs were made. One implant patient later underwent wrist arthrodesis. Concerning pain, the result was excellent in 12 and good in 9 cases. Extension-flexion of the wrist was 68% and the grip strength 82% of the contralateral. In one patient CHR significantly decreased as well as five ulnocarpal translations. However, the STT arthrodesis stabilized the scaphoid well. The scaphoid angle was 55° to 60° to the axis of the radius. Lunate changes or possible arthrosis is not mentioned upon. Lunate removal and implant use were not recommended. Failures were, based on the data provided, 39%.

Voche et al. (1992) published on 16 patients with Decoulx's classification of stage III in 13 and stage IV in 4 patients. Additionally, 10 silicone implants were placed. The average follow-up was 2.2 (0.5-4.1) years. Three patients were completely painfree. Most patients continued to have some pain, in two pain remained unchanged, and two were worse. Grip strength was 55% of the contralateral. Extension-flexion was 38% of the contralateral, ulnar deviation 56%, with radial deviation 0°. Patients were, with two exceptions, dissatisfied with their wrist ROM. CHR remained unchanged, ulnar translation increased in one patient. RSA was 46°. The scaphoid was too vertical in two, and too horizontal in two. Arthrosis of the radial styloid region appeared in five (32%) and in the radioscaphoid region in four, with a total of 56%. Recovery took an average of 5 months, and five patients were able to continue with the previous and eigth with modified or other work. Two failures were detected: PRC was done in one and arthrodesis in another. One of them had an implant, as well. The summary highlights a precise operative technique to determine the correct scaphoid angle. Arthroscopy was recommended for the evaluation of the joint surfaces. Stage IV is not suitable for STT arthrodesis. Most patients evaluated limited ROM as greatest disadvantage of the operation.

Minami et al. (1994) had 15 patients with STT arthrodesis in whom the lunate was replaced by a ball-like palmar longus graft. One patient was at stage IIIA, 11 at stage IIIB and 3 at stage IV. The monitoring was for 4.7 years. Seven patients were painfree, two had severe pain, others mild pain. Grip strength improved by 37%, being 73% of the contralateral. ROM decreased, extension 23%, flexion 18%, and radial deviation 63%. There were no problems in union healing, CHR improved from 0.48 to 0.53, arthrosis developed for five and was mild in two;

two were subjected to arthrodesis. The measure was considered appropriate at stage IIIA and stage IIIB.

Tränkle et al. (2000) published a study of 26 patients with a follow-up of 2.9 (0.8-6) years. Lichtman stage was III. Pain on the VAS scale 0-100 was on average 16.4 at rest and 33.7 at exertion (preoperatively 58.4 and 82.5). DASH was an average 24.8.at follow-up. Grip strength was 71% of the contralateral, extension-flexion 63%, and deviations 51%. A non-union had to be operated on for two, and one had an arthrodesis of the wrist because of pain.

Meier et al. (2004) published data on 59 patients followed for a mean 4 (2-8) years. Lichtman stage was in one II, in 14 IIIA, in 35 IIIB, and in 9 IV. All were subjected to STT arthrodesis and interosseus posterior nerve resection. The scaphoid was fused at about an 60° angle. Pain was evaluated on a VAS scale 0-100. Preoperatively, VAS was at rest 56 and during exertion 87, at follow-up, 12 and 41. The modified Mayo wrist score was 63 and DASH score 28. Extension-flexion was 67°, 60% of the contralateral and 81% of the preoperative. Radioulnar deviation was 31°, 52% of the contralateral. Grip strength improved significantly, from 45 kg to 52 kg. A nonunion was found in 9 patients (15%). Six of these were operated on. There were 13 patients (22%) with radioscaphoid arthrosis, 10 of these at the radial styloid. A styloidectomy was made for five. The treatment alleviated pain and produced acceptable ROM and grip strength. The authors stated that STT arthrodesis is essentially a salvage measure.

Yasuda et al. (2005) published on a series of 10 patients with Lichtman stage IIIB with a follow-up of 4.4 (0.8-9.1) years. All had an STT arthrodesis. Eight patients were painfree, two had mild pain. Extension-flexion was 60°/33° and grip strength 22.8 kg, 80% of the contralateral, a significant change compared to preoperative. All the arthrodesis united well, and no arthrosis occurred. RSA was 67°, the contralateral 69°. The authors recommended a scaphoid fusion at an angle of 60° to 70°. Everyone returned to work after about 4 months. The authors also considered the short-term result of a short follow-up notable because it is a case of young working-age patients.

Das Gupta et al. (2003) presented two series of Kienböck's patients. 13 patients were treated by STT arthrodesis, and 36 patients by radial shortening osteotomy. The average monitoring times were 2 years (STT group) and 6.9 years (RSO). In STT group DASH was 19 and MWS 70, extension/flexion was 68° and grip strength 68% of the healthy side. The corresponding numbers for RSO were 13, 85,106° and 83%.

Van den Dungen et al. (2006) presented 19 patients treated conservatively and 11 treated by STT arthrodesis (Table 5). The results of conservative treatment are presented earlier (Table 2). In STT group the average monitoring time was 14 (6-18) years. Lichtman stage was II in one and III in ten patients. STT arthrodesis did not

improve the clinical result. Significant differences were encoutered in parometric pain, ROM and in disability days after operation in favor of conservative treatment. In both groups, progression of Lichtman stage (cons. 53%, STT 64%) and arthrosis (cons. 42%, STT 55%) were nearly same, but in STT fusion there were more lunate fractures. The authors concluded that conservative treatment seems to be viable option in Kienböck's disease with at least potential complications.

Lee et al. (2012) published on 16 patient records with Lichtman's stage IIIB. In addition to STT arthrodesis, a lunate excision was made. The monitoring was for 5.6 (4-9) years. Extension slightly improved. Grip strength improved markedly, from 57% to 83% of the contralateral and the modified Mayo wrist score also, from 47 to 71. In 14 patients, ulnar translation of the scaphoid increased, and radioscaphoid arthrosis occurred in 4 patients.

2.11.7.2. Scaphocapitate arthrodesis

Sennwald and Ufenast (1995) published 11 patient records with Lichtman stage II in one, stage IIIA in four, and stage IIIB in six patients. The lunate was left in situ. The arthrodesis was fixed with lag screws, and corticocalcellous graft came from radius. The average follow-up was 2.9 (1-4.7) years. Two of the patients were re-operated on to remedy a nonunion. In one patient, the result was poor because of persistent pain. Seven patients were painfree, and three had pain during exertion. Nine patients were able to work earlier, one changed his work, and one was unable to work. Extension-flexion was 64°, 47% of the contralateral, and decreased by 52%. Grip strength was 39 kg, 72% of the contralateral. The effect on pain was good, and the procedure was recommended in advanced cases.

Rhee et al. (2015) published on a Mayo Clinic series with 27 patients. Of these, stage IIIA was that of 10, stage IIIB of 6, and stage IV of 11 patients. The monitoring was for 5 (1-16) years. In addition, 30 different procedures were performed in connection with the arthrodesis, including a partial resection of the lunate in 12, removal and interposition of the lunate in one, and removal of a lunate fragment in four. The modified Mayo wrist score was good in 13%, moderate in 46%, and poor in 41%. ROM decreased significantly, extension 11°, and flexion 14°. Grip strength improved significantly, from 19 kg to 24 kg. Pain decreased in 20, did not change in 6, and worsened in one patient. Of the 27, 20 patients returned to their former jobs, 3 were limited, and 4 were disabled. Wrist collapse progressed, and ulnar translation increased, but these changes did not correlate with the symptoms; 19% of these patients had complications, and in 41% of the patients, arthritic changes progressed. There were no bone-union problems. Two patients had arthrodesis of the wrist. According to the authors, patients should be informed about potential limitations of ROM.

2.11.7.3. Capitohamate arthrodesis

Biomechanical research has shown that CH arthrodesis does not reduce stress on the lunate (Horii et al. 1990). However, capitohamate arthrodesis has been used to treat Kienböck's disease, and initially the method was launched by Chuinard 1985.

Inoue (1992) published data on eight patients, all of whom had ulna-neutral or -plus variance. Stage II was the rating in five and stage III in three patients. The monitoring period was 3 (2-5) years. There were no complications. Six patients were painfree, and two had slight pain upon exertion, but everyone was able to do their jobs, for six of whom was heavy manual work. Extension-flexion slightly improved from 76° to 78°. Grip strength improved by 20%, being 92% of the contralateral. Lunate stage improved in one, from stage II to stage I and deteriorated in one from II to III, the others remaining unchanged. CHR remained unchanged at 0.50.

Oishi et al. (2002) published data on 45 patients with Lichtman stage I in 5, II in 13, and III in 27. Minus variance occurred in 55%. The monitoring was for 2.6 (0.3-8.9) years: 17 (38%) were painfree, 25 were somewhat relieved of pain, 2 were unchanged, and one grew worse. ROM did not change significantly. Grip strength improved from 52% to 72% of the contralateral. CHR remained unchanged at 0.49. Ulnar variance did not affect the results. In three patients, pain continued, and these were considered as failures; all three were at stage III.

2.11.7.4. Radiolunate arthrodesis

Tambe et al. (2007) published six patients' data in which the degree of disease was IIIB or IV, associated with local cartilage damage. The situation was determined by arthroscopy. First, the joint surfaces of the lunate and the fossa radius were revised, and the necrotic area was removed. Arthrodesis was done with a corticocancellous bone block, which was attached with K- wires. The monitoring period was 5.6 (2-9) years. Two non-unions were found, and in one patient, arthrosis progressed. These were treated with a wrist arthrodesis. No patient was completely painfree. Preoperative VAS was 7.3 and at follow-up 6 (3-10) and DASH score respectively preoperative 66.9 and 41. Failure rate of 50% did not support use of the measure.

Partial arthrodesis of the wrist, especially STT and scaphocapitate one, have proved to be beneficial for advanced lunatomalacia, but disadvantages are ROM deterioration and development of arthrosis of the radioscaphoid joint.

2.11.7.5. Temporary arthrodesis

Temporary STT joint fixation with Kirschner wires has been used in conjunction with revascularization of the lunate, as well as with a tendon ball implantation to stabilize the scaphoid during the healing phase (Yajima et al. 1998). Single such cases have been published in the treatment of Kienböck disease in children and adolescents (Shigematsu et al. 2005).

Ando et al. (2009) published data from six patients of an average age of 13.8 (9-17) years. Lichtman classification stage was in three patients at IIIA and three at IIIB. Ulnar variance was -0.4 (1 - -2) mm. The wrist was immobilized for an average of 2 months, and the pins were removed on average after 4 (3-6) months. The monitoring was 1.9 (0.6-4) years. Patients became painfree, extension-flexion improved from 94° to 145°, and grip strength from 52% to 86% of the contralateral. Lunate sclerosis and fragmentation improved, but lunate deformation was incompletely repaired. CHR was preoperatively 0.49 and at follow-up 0.50. MRI control had almost normal intensity in T1 and T2 images. One complication was a pin infection, that was treated with antibiotics. In one patient, the pin had to be replaced after volar migration. Treatment outcome was excellent. Briefness of immobilization and low risk from this operation were considered as benefits.

2.11.8. Treatment of advanced Kienböck`s disease

Lichtman stage IIIB and IV represent a far advanced stage of the disease. Arthroplasty, RSO, partial arthrodesis, and proximal row carpectomy have been reported in the literature for stage IIIB. At stage IV, suitable are PRC in some instances, wrist arthrodesis, and wrist arthroplasty.

2.11.8.1. Proximal row carpectomy, PRC

In PRC, the scaphoid, lunate, and triquetrum are removed. Of the several indications for PRC in the literature, the most common are a SNACK wrist deformity caused by a scaphoid fracture and a SLAC wrist deformity caused by ligament injury as well as a long-standing lunate dislocation and Kienböck's disease. Prerequisite for the measure is an intact cartilage of the proximal head of the capitate as well as in the lunate fossa of the radius. As a result of the resection, the wrist becomes a hinge joint, although there is some translation and rotation movement in the radiocapitate joint. The circumference of capitate's head is approximately 60% of that of the radius fossa both in the PA- and lateral X-rays. So, the load on the fossa is higher than the load of a healthy lunate (Imbriglia et al. 1990). However, in their material of 27 patients, including 6 Kienböck's disease, the clinical result after an average monitoring time of 4 (2-8) years was good. One patient suffered persistent pain and had radiocarpal arthrodesis later. 24 patients were able to continue their former job and three were retired (3/19 of manual workers). Extension-flexion was improved in all patients from 65° to 84°, but all cases had limitation of radial deviation. Grip strength was an average 80% of the healthy side. Radiological results were not presented.

Tomaino et al. (1994) published on 23 wrists with a follow-up of an average 6 years. Of these, Kienböck's disease was present in 8, with mean age 34 (18-59)

years and a follow-up 4.6 (2-9) years. Three had limitations in heavy work, and two had minimal arthrosis in the radiocapitate joint. Extension was 36° and flexion 33° and grip strength 85% of the contralateral in this subgroup.

Begley and Engber (1994) published on 14 patients, 5 of whom were at stage IIIA and 9 in stage IIIB. The monitoring was for 3 (1-8) years. At follow-up, 7 were painfree, 4 had mild pain, and 3 had some pain-limited activities. ROM improved in 11 patients to 68%, and grip strength was 72% of the contralateral. All patients were able to work. Two had arthrosis.

Nakamura et al. (1998) compared PRC and partial arthrodesis methods in 20 patients with stage IIIA/ 4, IIIB / 10 and IV / 6 patients. Seven patients underwent PRC. For the arthrodesis, 5 were in the STT, 4 in the scaphocapitate, 3 in the radiolunar, and 1 in the lunocapitate joint. Concerning pain, ROM, and grip strength, the result was better than after PRC, but this difference was non-significant. The authors recommended STT arthrodesis and tendon ball arthroplasty for advanced Kienböck's disease.

Jebson et al. (2003) published on 20 patients, but the study did not include Kienböck patients. The monitoring was 13.1 (10-17.2) years. Two had arthrodesis due to pain. Of 18 patients, one had severe pain, and 16 continued in their work. Four had severe arthrosis (20%). ROM was 63% and grip strength 83% of the contralateral.

DiDonna et al. (2004) published on 22 PRC cases including 7 with lunatomalacia, followed for 10 years. Four (18%) had arthrodesis, and all failures were with young people, aged 35 or younger. The same series was reported on (Wall et al. 2013) after 20 years of follow-up. Now 16 patients (with 17 wrists) attended the follow-up. During the follow-up period, an arthrodesis was performed on 6 wrists, and the remaining 10 of 11 patients had QuickDASH 16 and PRWE (Patient-Related Wrist Evaluation) of 26. Extension-flexion was 68° and grip strength 72% of the contralateral. The survival rate was 65%, and the worst result was found in the age group 35 to 40 years, for whom surgery was not recommended.

Most publications comprise mixed types of patients including, in addition to Kienböck patients, other indications, as well. Chim and Moran (2012) published results from six studies with 147 patients, of whom 55 (32.5%) had Kienböck's disease. There were 21 failures (14.3%) which ended up with arthrodesis. In three reports DASH score averaged 21.5. ROM remained unchanged in relation to preoperative (approximately 73°) and grip strength was 68 % of the contralateral. 79% had arthrosis in the radiocarpal joint, mild in 43% and severe in 35%. Arthrosis did not significantly correlate with the symptoms. Arthrodesis was done an average of 53 months after surgery, and the failures were distributed fair evenly across the various diagnostic groups. Failures were concentrated in the age group under 35.

Ali et al. (2012) published on 81 PRCs followed for 19.8 (15.1-36.5) years, including 13 Kienböck patients. Twelve (14.8%) had late-on wrist arthrodesis. In 27 patients, pain was relieved (44%), but 74% were dissatisfied with the outcome. DASH averaged 25.2, PRWE 32.2, and MWS 61.8. ROM did not change significantly, grip strength decreased from 37 kg to 31.6 kg, 48% of the contralateral. Radiological results were available for 27 patients, of whom 6 had been fused and 19 had arthrosis changes in the radiocapitate joint; 52 patients needed daily medication.

From the Mayo Clinic has been published in addition to the previous one another series with 144 PRC patients (Wagner et al. 2016). Kienböck patients numbered 33. The follow-up time was 13.4 (2-47) years. Pain relieved in 76% of the patients. DASH was 25.2 and MWS 64.9. Revision surgery was required in 17 patients (12%) at an average of 44 months.The result was better if surgery was performed in patients over 40 years of age, in Kienböck's disease ,for those who were not laborers, and in those who had been subjected to interosseus posterior neurectomy. Moderate or severe arthrosis existed in 45%, but arthrosis did not correlate with clinical outcome or need for revision surgery.

Three studies included only Kienböck's patients. De Smet et al. (2005) published series of 21 patients with advanced disease (stage III-IV). The mean monitoring time was 5.6 (1-11.5) years. As complications they noted two CRPS 1 and one superficial wound infection. Pain was absent or mild in 13 patients, moderate in 3 and severe in 5, including forementioned two CRPS complications. The mean DASH score was 22 (0-78) and PRWE 30 points (0-87). Wrist motion increased slightly, and the grip strength was 65% of the healthy side. Ten patients went to their former work and five changed to lighter ones, one was retired and three were unemployed at the review, including two CRPS patients. The authors recommend PRC for all stages III-IV of Kienböck's disease.

Croog and Stern (2008) published on 18 Kienböck patients (Table 5). Drop-out of the initial material, 21 patients contains 3 patients, who failed. Stage was IIIA in 5, IIIB in 12, and IV in one. The three failure patients had one stage IIIA and two IV. They had radiocapitate arthrodesis because of persistent pain after an average 23 months postoperatively. The follow-up time was 10 (4-17) years. Seven patients were painfree, 9 others had mild pain, and 2 moderate pain In the non-failure patients, the QuickDASH score was 12 (0-50) and in MWS 84 points. The average extension-flexion was 105°, 78% of the contralateral and grip strength 35 kg, 87% of the contralateral. Degenerative changes occurred in 87% of patients, but these changes did not correlate with the clinical outcome. Of the 16 patients who were employed, 4 did heavy work.. There appeared no difference between stage-IIIA- and -IIIB patients, although stage-IIIB patients had more cartilage changes.

Lumsden et al. (2008) published on 13 PRC patients followed for 15 (11-20) years (Table 5). Stages were IIIA and IIIB. Drop out was 23%. At follow-up, 5 patients were painfree, 6 had mild pain, and 2 had pain upon exertion. Extension-flexion was 88°, 73% of the contralateral and grip strength 32 kg, 92% of the contralateral. Motion and grip strength were better than preoperatively. All patients were at work, 7 of them doing manual work. Nine patients had degenerative changes in the radiocapitate joint, three of them moderate and one severe. Clinical and radiological findings did not correlate. There were no complications. PRC was thus considered to be a good treatment for advanced Kienböck disease.

2.11.8.2. Denervation

Particularly in Middle Europe, Wilhelm's (1966) wrist denervation has been used in advanced stage-IV lunatomalacia. Buck-Gramcko (1977) published from the German-speaking region on a series of 195 patients from eight outpatient clinics, of whom Kienböck's disease was found in 32 patients. The average follow-up was 4.1 years. In 25% of these patients, the result was unsatisfactory, in 24 (75%) satisfactory. Seven were painfree, and 14 had pain during heavy strain, 9 during light strain, and 2 during all activities. In five patients, degeneration increased during the follow-up period, but no Charcot-type joint changes were observable.

Buck-Gramko (1993) published on another 61 patients with Kienböck disease, in which for 47 patients, denervation was combined with another procedure, in part as partial denervation. Of the patients, 88% were quite satisfied, and 76% had no pain or had pain only during heavy manual work. Approximately the same result was achieved by denervation alone. Total or partial denervation proved beneficial either as an additional measure or alone in stage III to IV.

Schweizer et al. (2006) published on 71 patients with total denervation with a follow-up of 9.6 years. Kienböck's disease was present in 11 (15%); 22 patients were completely painfree (18.5%), 13 had mild, 20 moderate, 11 significant, and 4 severe pain, and 61 patients (87%) were in their former job. Failure rate was 12.6%, and 9 patients underwent additional measures.

Braga-Silva et al. (2011) published on 49 patients, of whom 13 had Kienböck`s disease, 19 had a SLAC wrist, and 17 primary osteoarthrosis as an indication of total denervation. The results were not presented by patient group, between which no differences were noted. The monitoring was for 6 years. Pain was slighter in 80%, grip strength improved from 43% to 69% of the contralateral, and ROM improved significantly. Extension-flexion improved from 40° to 52°. Arthrosis changes were aggravated in 34 patients without significant difference between the groups. Four patients had a neuroma of the cutaneous branch of the radial nerve in the area of the index finger.

Denervation could come into question, according to these studies, in a situation in which one alternative was a wrist arthrodesis, but the patient, knowing its limitations, would not agree to this action. Denervation especially as combined with other measures may also be advisable (Buck-Gramcko 1993).

2.11.8.3. Wrist arthrodesis

Total arthrodesis of the wrist is considered an excellent choice in the treatment of painful arthrosis (Houshian and Schröder 2001). Their 42-wrist fusion series included 8 operations due to Kienböck's disease. Of the patients, 32 were painfree, and grip strength was 88% of the contralateral. Non-unions in this series, where an AO titanium fusion plate had been used, numbered only 3, and in total 12 reoperations (28%) were done.

Kalb et al. (1999) published on 64 patients of whom 35 attended a follow-up study after 2.1 (0.5-5.2) years. Four (11%) had Kienböck's disease-related arthrosis. Osteosynthesis was done with a plate. Pain on the VAS scale of 0-100 was preoperatively 83 and at follow-up 33. In more severe strain only 3 of 35 patients were painfree. DASH for all patients averaged 45.6 (4.2-86.7) and optional DASH 60.6. Functional deficiency was related to the problems caused by stiffening of the wrist, for example in self-care like hygiene. Grip strength was 64% of the contralateral. However, 62% of the patients were satisfied with the method.

Sauerbier et al. (2000) had 60 patients, 6 with Kienböck`s disease. The monitoring period was on average 3 years. VAS pain on the 0-100 score was preoperatively at rest 58 and during exertion 89, at follow-up 16.5 and 54; 80% had pain during various activities, and 70% of the patients returned to their former jobs. DASH score was 51.4. Grip strength was 50% of the contralateral; 23 (35%) patients were subsequently subjected to additional procedures, of these, 5 (8%) due to a nonunion. Although 80% of patients had functional deficiencies, 80% were satisfied with the procedure.

2.11.8.4. Total wrist arthroplasty

Total wrist arthroplasty is an alternative to total wrist fusion. Because prostheses and operative techniques are developing, it has been possible to improve results. In short-term follow-up (2.3 years), with the Maesto prosthesis, among 23 procedures, 2 for lunatomalacia, DASH was 31 and MWS 54, and VAS improved from 8.0 to 2.2 (Nydick et al. 2012). This series included one failure due to a deep infection.

Boeckstyns et al. (2013) published a 5-year follow-up with a Re-motion TWA prosthesis. Patients with 52 wrists attended the follow-up, most of the wrists rheumatoid, only one with Kienböck's disease. Five had been revised, and 6 had radiological signs of prosthesis loosening, and 11 had in addition osteolysis

without loosening. Pain (VAS from 67 to 27) and DASH (from 58 to 42) improved significantly.

Segerfors et al. (2015) published on 189 patients (219 wrists). The data involved three different prostheses. During 7 (2-13) years of follow-up, survival improved from 81% to 95% mainly in those with the Maestro prosthesis. The preoperative severe destruction of the wrist affected survival. Rheumatoid arthritis in this study affected 185, but the study included no Kienböck patients.

Until now, total wrist arthroplasty has not been used to a large extent in the treatment of advanced stage-IV Kienböck's disease.

2.12. SUMMARY

Based on this extensive literature review, the fact is that only a limited number of findings have appeared on the long-term results of Kienböck`s disease treatment compared to the total number of publications on this disease. The follow-up time was, as described in 33 articles concerning 21 series, from 10 to 15 years, in 8 articles 15 to 20 years, and in only 5 publications more than 20 years. Seven articles reported on conservative treatment or the natural course of the disease, 11 on the so-called "leveling procedures" (RSO, RCWO, ULO), 4 on interposition-arthroplasty, 3 on revascularizations of the lunate as well as core decompression, and 2 on implant-arthroplasty and PRC, miscellaneous data excluded, and one on STT union. All these studies were retrospective.

Kazap and Daecke (2010) published a summary of the long-term results of Kienböck's disease (more than 10 years of follow-up). With decompression osteotomies, 20 to 67% were painfree, ROM was 80 to 98%, disease progression was found in 20 to 50% and arthrosis occurred in 25 to -73%. The corresponding figures for revascularization were 35 to 72%, 68 to 81%, 11 to 100%, and 32 to 100%. A general care algorithm could not be presented, as the series were poorly comparable among themselves.

3. AIMS OF THE PRESENT STUDY

The aims of the present study were:

I. To evaluate the natural outcome of Kienböck's disease
II. To evaluate the long-term outcome after silicone implant arthroplasty in Kienböck's disease
III. To evaluate the long-term outcome after radial shortening osteotomy for Kienböck`s lunatomalacia
IV. To evaluate the outcome after Titanium lunate arthroplasty

4. PATIENTS AND METHODS

The patients with Kienböck's disease were identified from our files in Orton Orthopaedic Hospital (Studies I-III) and in Tampere University Hospital (Study IV). Study I comprised the patients with radiologically diagnosed Kienböck's disease without any treatment. The patients were found from a register of the radiological department's files under heading "osteonecrosis" or " avascular necrosis". These patients were treated in years 1982-2006. Study II included the patients treated with silicone lunate arthroplasty between 1971 and 1986. In Study III the patients were treated with radial shortening osteotomy in years 1978-1988 and Study IV included the patients, which were treated with titanium implant arthroplasty during years 2001-2010 (Figure 9).

In Study I two patients could not participate because the poor physical condition and long-distance travelling. One patient was excluded because short follow-up time (5 years) and also because the initial X-rays and documents were missing. In this study the patients did not receive any treatment, although the treatment option at the first consultation had been, in addition to thoughtful observation for five wrists, splinting during painful periods for one patient and surgery for three. The one who was recommended the splint did not use it and the three who were recommended surgery adopted the treatment due to slight symptoms and fear of surgery.

In Study II 16 patients were died, 11 denied to participate and 13 could not been contacted. Four patients had very poor condition and illnesses preventing to participate.

In Study III two patients were excluded because they were reoperated because of progressed disease. One underwent silicone implant arthroplasty 2 years after osteotomy and one had wrist fusion 16 years after RSO. These two patients participated the follow-up examination, but the results were excluded.

In Study IV all patients were included at the follow-up evaluation.

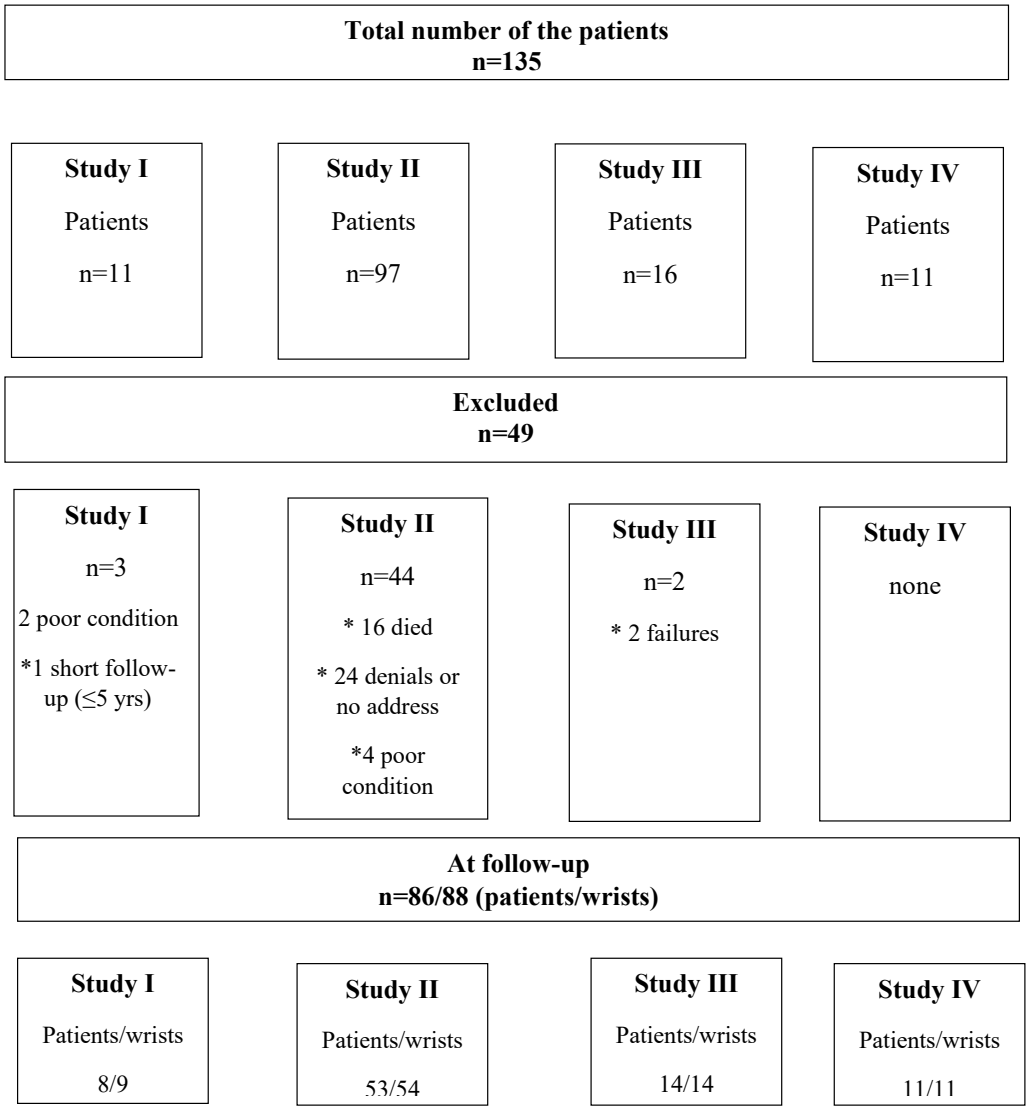

Figure 9. Algorithm for Kienböck patients

4.1. INCLUSION CRITERIA

All patients were symptomatic and the diagnosis was based on plain radiographs. No one had arthritic or other diseases in the wrist region, neither fractures nor joint injuries beforehand needing some treatment. In Study II three patients had very mild degenerative changes of the wrist joint not preventing the treatment.

The indication for the operations was wrist pain, which usually limited the physical activity and working ability. They all have had some conservative treatment without success and the symptomatic times were usually long before the treatment.

Pre-and postoperative data came from the patient's medical records. At the first consultation all the patients underwent a clinical and X-ray examination. No functional or pain scorings were used at that time. The patients were followed at the routine clinical and X-ray follow-up examinations usually at 12 months and later on as needed, most of them annually for many years.

4.2. OPERATIVE PROCEDURES

Patients in Study II were operated with technique presented by Swanson 1970. A dorsal approach was used and the lunate was removed usually piecemeal. The proper size of implant was tested with trial implants of four sizes. The stability of the implant was improved with a stem, which was inserted into a hole maid in the triquetrum. No additional fixation was used. The volar capsule was carefully preserved and repaired, if necessary, and the dorsal wrist capsule was tightly closed. The wrist was immobilized for six weeks and then rehabilitation was started, mostly without any supervised physiotherapy.

In Study III the radial shortening osteotomy was done in wrists with ulnar minusvariance without arthrosis. The osteotomy was performed by dorsal approach and transversally in the proximal metaphyseal area. T-plates were used for fixation of the osteotomy and in three patients fixation was achieved with Kirschner wires. The wrists were immobilized for a mean six (range, 4-10) weeks. All fixation materials were removed later on.

In Study IV the operation technique was principally the same as in Study II. The titanium implant and the operation technique were introduced by Swanson et al. (1997) and they reported their results at the same time. The primary fixation of the implant was made with a thread trough the scaphoid and triquetrum bones and via the holes in the implant. Five implant sizes were available. No additional fixation or partial arthrodesis was done. The wrist was immobilized with a plaster cast for six weeks and thereafter with a splint for four weeks during night.

In all treatment studies the wrists were X-rayed after the operation and at the control visits. The guidance for mobilization, performed by the patient, was given after immobilization.

4.3. FOLLOW-UP EXAMINATIONS

The examination regimes were the same at the follow-up in all four studies. Questionnaires were send by mail to patients, along the study invitation. The questionnaire comprised questions concerning demographics, symptoms of the operated hand, subjective satisfaction, pain evaluation on a visual analogic scale (VAS) and the ability to work. They also completed DASH questionnaires.

Pain level was recorded in patient-generated visual analogic scale, VAS (range 0-10; 0= none, 10= maximal pain) (Flaherty 1996). VAS was recorded at rest, during motion, mild and heavy stress (like shoveling or hammering).

DASH and Optional (work or hobby related) DASH questionnaires (Hacklin et al. 2009) were checked. At follow-up examination the Mayo wrist score (MWS) was calculated (Cooney et al. 1987). This was selected because PRWE (Patient-Rated Wrist Evaluation questinnoire) was not validated in Finnish at the time of follow-up (Sandelin et al. 2016) and also because MWS was commonly used in studies of Kienböck's disease.

The clinical notices were checked and completed, e.g. a possible history of other diseases, wrist traumas and the changes in working conditions and ability. Clinical findings like swelling, local palpation or motion tenderness and crepitation were registered, as well as the possible complications and later measures.

Active ROM of both wrist joints, flexion-extension, radial and ulnar deviation and pronation-supination were measured (Solonen and Nummi 2012), as were grip and key pinch strengths in mean value (kg) of three measurements. The measurement tools and technique were the same in all Studies.

PA-and lateral X-rays of both wrists were taken in standard positions (Yin et al. 1996). The stage of Kienböck's disease was evaluated according to Lichtman and Degnan classification (1993). Carpal collapse was evaluated by carpal height ratio (CHR) (Youm et al. 1978), as well as Ståhl index (Ståhl 1947) and lunate-covering ratio. Carpal height ratio was measured by dividing the height of the carpus by the length of the third metacarpal (normal 0.54; SD 0.03) and carpal ulnar distance ratio (CUDR) by dividing the carpal-ulnar distance by the length of the third metacarpal (normal 0.30; SD 0.03). Ståhl index was relation of the height to the breadt of the lunate bone in percentages (normal ≥ 50). Ulnar variance measurement was done using the method presented by Gelberman et al. (1975) (Figure 6).

In the evaluation of the arthrosis the scores used are descriptive or numerical with increasing severity or wider location (Knirk and Jupiter. 1986, Wollstein et al. 2012). In our calculation an arthrosis index, we categorized radioscaphoid, scaphotrapezoid and scaphocapitate joints in arthrotic changes from 1 to 5 (1= normal joint, 2= joint-line narrowed, 3= joint-line narrowed and sclerosis, 4= joint-line narrowed+ sclerosis+ osteophytes and 5= joint deformed). Total arthrosis index varied from 3 to 15 and these quantitative values were used for comparisons. Attention was paid to any radiological signs of bone cyst formation in the carpal area and alignement of the carpal rows and bones with the implant.

4.4. STATISTICAL ANALYSIS

Frequencies, proportions, ranges, means and standard deviations (SD) (Study I-III) and 95% Confidence Intervals (95% CI) (Study IV) served as descriptive statistics. Pearson chi-square statistics, t-tests and analysis of variance were applied to calculate statistical differences in pain. $p \leq 0.05$, two-tailed was considered a statistically significant threshold. All statistical analyses were performed with SPSS®, version 20.0 (Study I-III) and version 22.0 (Study IV) (IBM, SPSS, Inc., Chicago, Illinois, USA).

The x^2- test served for analysis of the incidence of silicone cyst formation and radiological outcome. Analysis of variance (ANOVA) was for pain, ROM, and function. Differences in categorical variables were tested with Pearson's x^2 or Fischer's exact test (Study I).

The differences between the wrists for ROM (range of movement), strength and radiological findings were determined by using Pearson's correlation test (Study II).

The differences between the wrists for ROM (range of movement), strength and radiological findings were determined by using *t*-test (two-tailed). The paired sample *t*-test was used individually for ROM and grip strength between the first and follow-up examinations (Study III).

A two-tailed Student *t*- test were used in comparison the preoperative ROM, strength, and radiological measurements between the affected hand and the contralateral hand. The paired-sample *t*-test compared the change within the same hand (preoperative vs. postoperative). Frequencies, proportions, means, ranges, standard deviations (SD), (Study IV).

5. RESULTS

5.1. LONG-TERM NATURAL OUTCOME (7 TO 26 YEARS) OF LICHTMAN STAGE III KIENBÖCK`S LUNATOMALACIA

Age at onset of symptoms averaged 34 (range, 15–44) and at first consultation 43 years. Of eight patients, five recalled some history of prior wrist trauma. Time from onset of symptoms to first consultation with one of the authors ranged from 0.5 to 31 (mean, 9.2; median 4) years. There were six right-handed patients, 7 men, and the dominant wrist was involved in six of the 8. At final evaluation, mean age was 60.7 years (range, 40-72). Follow-up time from onset of symptoms was 27.3 years (range, 10-38). The initial Lichtman stages were IIIA in seven wrists, and stage IIIB in two. Initial ulnar variance ranged from –5 to 2 mm with a mean of –1.3 mm.

At follow-up, VAS pain averaged at rest 3.1, in wrist motion 3.4, in slight exertion 3.5 and in heavy exertion 5.2. One patient was totally painfree at rest and during motion. DASH averaged 11.3 (range, 0-39.2), optional DASH 18.0 (range, 0-56.3), and Mayo wrist score 70.0 (range, 55-85), (Table 6).

Lichtman stage remained the same in five at stage IIIA, in one at stage IIIB, but two stage IIIA and one IIIB wrists deteriorated to stage IV. The shape of the lunate bone at follow-up had improved in two wrists and remained the same in same in three but deteriorated in three. Significant differences between the affected and contralateral wrists at follow-up were detectable in RSA (59° vs. 51°, p=0.029), in Ståhl index (36 vs. 53, p= 0.03), lunate-covering ratio (0.77 vs. 0.66, p= 0.024) and arthrosis index (5.4 vs. 3.1, p= 0.007). Arthritic changes had progressed in eight wrists of nine (89%) and were moderate in three wrists (index 7-9), but in no case was severe. Only one patient had no arthrosis at all, and the mean arthrosis index was 5.4 in the affected and 3.1 in the contralateral wrists. The radioulnar joint was normal in six wrists at follow-up, but mild arthrosis (index 2/5) was noted in one wrist and moderate arthrosis (index 4/5) in two. The contralateral radioulnar joint was normal in six wrists at follow-up and moderately arthritic in one. Ulnar variance was at follow-up mean -1.7 (-5 - +2) mm in the affected and -1.4 (-5 - +2) mm in the unaffected wrist.

No complications were noted.

ROM improved in 18 years: extension by 19%, and flexion by 15%, but not significantly. Extension of the affected wrists (mean 50°) reached 82%, flexion (mean 41°) reached 72%, radial deviation (mean 21°) 73% and ulnar deviation (mean 29°) 80% of the unaffected side.

Grip strength improved during the 18 years by 32% in the affected hand, whereas grip strength of the unaffected hand deteriorated 14% during that time. Grip strength (mean 38 kp) was 93%, and key pinch 97% compared to the contralateral hand.

Initially six patients had continued their earlier work, two had changed to lighter work. At follow-up three patients still continued working, and five were retired, none due to the wrist problem. The wrist symptoms had diminished during these years markedly in one patient and somewhat in one but remained unchanged in one and deteriorated in three; two patients did not respond. One patient considered his wrist interfering during activities in his daily life.None evaluated the result as excellent, one called it good, three fair and two said poor; two did not reply.

5.2. LONG-TERM OUTCOME (22–36 YEARS) OF SILICONE LUNATE ARTHROPLASTY FOR KIENBÖCK'S DISEASE

Age at surgery averaged 33 (range, 20–51) years; 28 (52%) were traumatic disorders. Time from onset of symptoms to surgery ranged from 8 to 180 (mean 29.7, median 19.5) months. At the time of the operation, 36 patients were engaged in heavy manual labor, 17 were doing light work; 33 (62%) patients had the disease in the right, dominant hand. Stage IIIA disease occurred in 32 wrists, 16 had stage IIIB, three had stage IV, and in three wrists, pre-operative X-rays were lacking. In 43 wrists, a negative ulnar variance ranging from –1 to –5 (mean –2.1) mm was measurable, and 6 wrists had a positive variance of mean 1.1 mm. Compared with the contralateral wrist, average loss was 21° of extension, 29° of flexion, 9° of radial deviation, and 11° of ulnar deviation.

At the follow-up pain on VAS averaged 2.2 at rest, 2.0 with motion, and 3.6 with slight and 5.3 with heavy exertion; 52% of patients had no pain at rest, 44% with motion, 21% with slight exertion, and only 11% had no pain with heavy exertion. DASH score averaged 25.4 (range, 0.8-52.6), optional DASH 27.0 (range, 0-81.), and Mayo wrist score 54.8 (range, 10-80), (Table 6).

The carpal height ratio (CHR) averaged 0.49 preoperatively in the affected wrist and 0.53 in the contralateral wrist, and carpal ulnar distance ratio (CUDR) at 0.32 and 0.33. Significant differences between the operated and contralateral wrists were detectable in the CHR and CUDR, radio-scaphoid angle, and lunate-covering index, but not in radioscaphoid angle or Ståhl index.

The carpal height ratio and lunate-covering ratio diminished, the radioscaphoid angle became bigger, but other radiological variables remained about the same. Our arthrosis index (3–15) averaged 3.4 pre-operatively, 3.6 at 1 year, 4.2 at 5 years, 4.0 at 10 years, and 7.7 at 27 years. Arthrosis was noted in 91% of patients.

The implant showed no deformation in 89% at 1 year, but only in 35% at 27 years. The radioscaphoid angle tended to increase. Stage of malacia or size or fit of the implant did not influence the radiological, clinical, or functional result.

Of the 53 patients, silicone cysts developed in 42 (79%). The first cysts were detected at a mean 6.1 (range, 0.6–20.5; median 3.7) years post-operatively in those 33 patients in whom we were able to detect the first cyst-development time point accurately. Cysts were detected in 31% at 1 year, 57% at 5 years, and 81% at 10 years. Cysts were detectable in all carpal bones as well as in the radius, ulna, and metacarpals. The number of bones affected by cysts ranged individually from 1 to 12. No cysts were detectable in 69% at 1 year, in 43% at 5 years, in 19% at 10 years, or in 22% at 27 years. Cysts in ≥ 4 bones were detectable in 6% (1 year), 10% (5 years), 37% (10 years), and 39% (27 years). At final review, in the 12 wrists without cysts, the implant remained in situ in 7, and in all but one of those, degenerative joint changes were minimal. That one wrist showed generalized synovitis, and all joint lines were narrowed. Of the other five wrists without silicone cysts, there was one permanent implant dislocation, two implants were removed due to dislocation, and one wrist was fused due to severe pain. One wrist was spontaneously fused due to post-operative infection. This was the only postoperative complication. Altogether 12 were removed, 3 in consequence of the dislocation and 9 in consequence of synovitis of the wrist leading wrist fusion in six patients.

Extension of the affected wrists reached 70% (38.9°/55.6°) of that of the contralateral wrists after 27 years, flexion 57% (33.1°/57.8°), radial deviation 64% (17.1°/26.7°), and ulnar deviation 67% (26.6°/39.5°). These differences were significant for all except the flexion. Six wrists were fused by surgery. Flexion was better than on the unaffected side in the operated wrist in one patient and remained the same in three, but extension failed to reach the contralateral level for any patient. Grip strength was significantly inferior (72%, 28.1/38.9 kg) in the operated hand.

Of the patients, 25 were still employed and 11 were retired due to wrist problems.

Wrists without cyst formation were less painful than the cystic wrists: VAS with slight exertion 1.2 vs. 4.3 ($p = 0.012$), and with heavy exertion 2.5 vs. 5.8 ($p = 0.012$). Wrists without cyst formation had better functional scores: DASH 15.5 vs. 27.7, DASH Optional 6.6 vs. 32.3, and Mayo Clinic score 64.2 vs. 55.9. Radiologically, CHR, Ståhl, and arthrosis indexes were related to silicone cyst formation. However, in wrists without cyst formation, significant differences between the operated and contralateral wrists were detectable only for the arthrosis index (4.6 vs. 3.0) ($p \leq 0.001$). Arthrotic changes were significantly more common and severe in the wrists affected by cysts (arthrosis index 10.2 vs. 4.5, contralateral wrist 3.3 vs. 3.0). In all those six wrists without cyst formation and degenerative joint changes (arthrosis index 4.6, contralateral wrist 3), clinical outcome was good. Thus, the very long-term radiological, clinical, and functional results were good in only 11%.

5.3. LONG-TERM OUTCOME (20-33 YEARS) OF RADIAL SHORTENING OSTEOTOMY FOR KIENBÖCK`S LUNATOMALACIA

Age at surgery averaged 31.4 years (range,16-45 years). Seven (43 %) had a low-energic trauma history. Time from onset of symptoms to surgery ranged from 6 to 54 months (mean, 22 months; median 23 months). At the time of operation, nine patients were engaged in heavy manual labor, and five were doing light work. All patients had the disease in the dominant hand; four of them were lefthanded. Lichtman stage II occurred in one wrist, stage IIIA in 11, and stage IIIB in one wrist. In one patient, the preoperative X-rays were missing. Ulnar variance ranged from -1 to -5 mm (mean -3.1 mm, in the contralateral wrists -1.9 mm). When compared with the contralateral wrist, average loss of extension was 16°, of flexion 25°, of radial deviation 10°, and of ulnar deviation 14°. Grip strength averaged 24 kg on the affected and 42 kg on the unaffected side.

At follow-up, VAS pain averaged at rest 0.9, in wrist motion 0.9, in slight exertion 1.7, and in heavy exertion 3.0 (mean of all 1.6). Twelve wrists were painless at rest, ten in motion, seven in mild and four in heavy strain. Three were totally painfree (21%). DASH averaged 6.1(range, 0-23.3), optional DASH 10.8(range, 0-37.5), and Mayo wrist score 79.3 (range, 60-95), (Table 6).

The Lichtman stage remained the same in one, was stage II, in seven was stage IIIA, and in one, stage IIIB, but two stage-IIIA wrists deteriorated to stage IIIB and two to stage IV. In one wrist at stage IV at final follow-up, preoperative x-rays were lacking. The shape of the lunate bone at the last follow-up was better but not normal in seven wrists and somewhat deformed in seven. Lunate inner structure was better in every patient (Figure 10, 11, and 12). No significant differences in radiological indexes between the preoperative and final follow-up were detectable in the operated wrist, except for the carpal ulnar distance ratio ($p=0.048$). Significant differences between the operated and contralateral wrists at final follow-up were detectable only in the Ståhl index ($p=0.001$) and in the lunate-covering ratio ($p=0.014$). The carpal height ratio remained the same at 0.50. Arthrotic changes were minimal, our arthrosis index was 4.4 in the affected wrist and 3.1 in the contralateral wrist.Arthrosis was noted in 71% of the patients. The radioulnar joint was normal in nine patients, mild artrosis (index 2/5) was noted in two patients, and moderate or severe arthrosis (index 4-5/5) in three, altogether in 36% of the patients. Ulnar variance was at follow-up a mean + 1.5 (0-5) mm. One patient had radial overgrowth and bowing after a radius fracture in childhood and ulnar variance –5 mm. At follow-up, after radial shortening by 10 mm, ulnar variance was +5 mm, and the radioulnar joint was arthritic (index 5/5). Limitation of prosupination was 10°, and it was painful (VAS 5). Another patient

had at follow-up an ulnar variance +5 mm without limitation of prosupination, and the radioulnar joint was almost normal (arthrosis index 2/5).

Complications were encountered in 6 of 16 patients (38%). In three patients, complications were connected with the progression of lunate collapse (19%). Of these three patients, one underwent silicone implant arthroplasty 2 years after osteotomy and one had wrist fusion 16 years after RSO. The patient had the implant had moderate clinical result. He was able to continue his work. After 25 years, the wrist was painful during severe strain (VAS 5). The radiocarpal and radioulnar joints were arthrotic (indexes 9/15 and 4/5). The DASH score was 10 and Mayo wrist score 80. The patient with wrist fusion was retired. That wrist was painless (VAS 0), DASH score 0, Mayo wrist score 40, and the radioulnar joint was arthrotic (index 5/5). These two patients were excluded from the follow-up results.The third patient was 16 years old at the time of surgery and Lichtman stage was IIIB. She underwent reoperation due to ulnar impingement (ulnar variance +2 mm) 25 years after RSO with ulnar shortening without success. After 26 years of follow-up, the wrist was painful (VAS max. 8), DASH score 23.3. The lunate was severely deformed, as it was before RSO, but the lunate inner structure was improved. No arthrosis was noted, but the wrist had the same VISI deformity as preoperatively. The aforementioned three patients were regarded as failures.

In three patients, complications were not related to the lunate bone itself. Two patients had refracture of the radius after plate removal. One of them was treated with a free bone transfer and cast immobilization. After 27 years, that wrist was painful upon strain, VAS 4. He was able to continue his work, and his DASH score was 10. The radiocarpal osteoarthrosis index was 5/15. The other one was treated with a free-bone transfer and Rush pin fixation. That wrist was at follow-up painful, VAS was at rest 5 and in strain 7 and Mayo wrist score 80. Radiocarpal and radioulnar joints were arthrotic (index 6/15 and 2/5), and supination was restricted. The third patient had overshortening of the radius and had ulnar variance +5 mm postoperatively. Ulnar shortening osteotomy corrected the supination restriction. After 20 years he was working as a truck driver, and had only mild pain on strain, VAS 2. He had no radiocarpal arthrosis but mild radioulnar arthrosis (index 2/5). His DASH score was 0 and Mayo wrist score 75.

ROM improved in 25 years: extension 12%, flexion 5%, radial deviation 47%, and ulnar deviation 7%, whereas ROM of the unaffected wrist deteriorated during that time: at extension 9%, flexion 13%, radial deviation 7%, and ulnar deviation 10%, Extension of the operated wrist reached 93% (56°/60°), flexion 76% (45°/59°), radial deviation 104% (28°/27°), and ulnar deviation 78% (29°/37°) of the unaffected side. Grip strength improved in 25 years by 54% in the operated hand but deteriorated by 10% in the other hand as did key pinch, 10% and 30%. Grip strength still was inferior by 5% (37/39 kp), but key pinch was 7% (9.2/9.6 kp) better than on the contralateral side.

Seven patients continued their earlier work, two had changed to lighter work, and five were retired, one due to the wrist problem, four because of age. Seven patients evaluated the result as excellent, four as good, and three as moderate. All except one would choose the same treatment again.

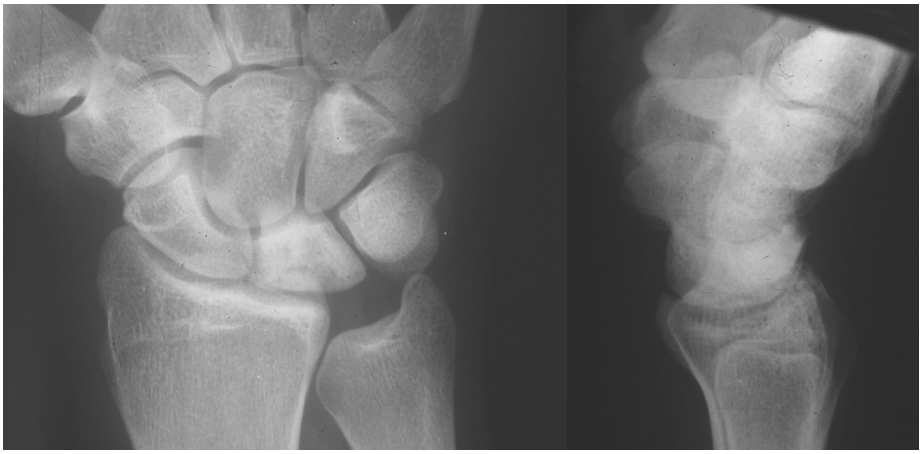

Figure 10. Radial shortening osteotomy
26-year-old man, stage II Kienböck's disease in the right dominant wrist. Ulnar variance -5 mm.

Figure 11. X-ray 2 months postoperatively.
The osteotomy is healing. Shortening of 3 mm was performed.

Figure 12. After 24 years follow-up.
The patient was painfree and able to work. Wrist motion was 91% and grip strength 108% of the healthy side. The lunate is slightly deformed, Ståhl index is 44, and carpal height ratio 0.51. The bone structure of the lunate is improved. Neutral variance is evident.

5.4. LONG-TERM CLINICAL OUTCOME AFTER TITANIUM LUNATE ARTHROPLASTY FOR KIENBÖCK´S DISEASE

Patient's age at operation was an average 47 (31-65) years. Of eleven patients, seven recalled history of prior low-energetic wrist trauma. Time of the onset of symptoms to the operation was an average 45 months (median 19 months). All were men, seven were righthanded, and the dominant wrist was involved in eight patients. Five men were in manual work, four in light work and two were retired because of age. The initial Lichtman stage was IIIA in six wrists and IIIB in five. All lunates were collapsed, 10 had fragmentation or coronal fractures and four patients had cartilage injuries in the lunate. One patient was previously treated by screw osteosynthesis and one had revascularization without success. Extension was 65%, flexion 63% and grip strength 55% of the unaffected side.

At follow-up, pain on VAS averaged at rest 0.5, at night 0.3, and with exertion, 2.7; seven of the patients had no pain at rest, nine had no pain at night, but only two had no pain with exertion. There was no pain with motion in 10 patients, none

had tenderness to palpation or swelling, one had some crepitus in the wrist. DASH score averaged 9.6 (range, 0-25.8), optional DASH 9.7 (range, 0-37.5), and Mayo wrist score 67.7 (range, 40-85), (Table 6). DASH score was 0 in three patients, and only one patient had a DASH score greater than 25. Three patients had poor MWS-score (40-60), two of them had experienced the dislocation of the implant and one had connective tissue disease affecting also the wrist (Table 6).

In radiological indexes compared to preoperative values only significant differences were noted in Ståhl index and in arthrosis index ($p<0.05$). Ståhl index was an average 66 and 49 in the contralateral side. CHR was an average 0.51 and 0.53 in the contralateral side. Arthrosis index was mean 4.4 and in contralateral side 3.0. Mild artrotic changes were noted in 45% and in radioulnar joint in 36% of patients (index 2.5/5).

No complications were noted primarly, but later two implants dislocated dorsally. They were not operated during the follow-up, but afterwards one of them had wrist fusion.

Extension (mean 48°), flexion (44°), and ulnar deviation (34°) of the affected wrists reached 71% of that of the contralateral wrists, and radial deviation (21°) 62%, after mean 11 years. These differences between affected and unaffected wrists were significant for all, $p < 0.05$. Movements were better than preoperatively. The difference was significant in radial deviation. The grip strength was significantly better than before surgery, $p<0.05$, but still significantly inferior in the operated hand, $p<0.05$, 81% (weighted 79%, mean 59.9 kg) of the healthy side.

Five patients continued in their former work, one had changed to lighter one, two were on sickleave for other reasons and three were retired because of age. Nine patients evaluated the result excellent, one good and one fair.

Table 6. Long-term results (mean ≥ 10 years follow-up) of Kienböck's disease in our studies

Authors	Year	N patient/ wrists	Treatment	Initial Lichtman stage I / II / III / IIIA / IIB / IV	Follow-up time years mean (min-max)	Pain VAS or presented numbers	Grip strength % of contralat.	ROM[1] ext/flex (°) or % of contralat.	DASH[2] mean (min-max)	MWS[3] mean (min-max)	Progression (in Lichtman stage), %.	Arthrosis presence %
Study I	2015	8/9	no	0 / 0 /- / 7 / 2/ 0	18 (7-26)	VAS at rest 3.1, in light strain 3.6, in heavy strain 5.2. No one painless.	93	50°/41° 82%/72%	11.3 (0-39.2)	70 (55-85)	45	89 DRUJ 38%
Study II	2013	53/54	SLA	0 / 0 /- / 32 / 16 / 3	27 (22-36)	VAS 2.2 at rest, 5.3 in heavy strain. No pain 11%	72	39°/33° 70%/57%	25.4 (0.8-52.7)	54.8 (10-80)	-	91
Study III	2014	14	RSO	0 / 1 / 11 / 1 / 0	25 (20-33)	VAS 1.6 no pain 3, in mild strain 7, in heavy strain 4	95	56°/45° 93%/76%	6.1 (0-23.3)	79 (60-95)	36	71 DRUJ 36%
Study IV	2018	11	TLA	0 / 0 / - / 6 / 5 / 0	11 (5-15)	VAS 0.5 at rest, 2.7 in strain. No pain 18%	81	48°/44° 71%/71%	9.6 (0-25.8)	67.7 (40-85)	-	45 DRUJ 36%

[1]Range of motion; [2]Disabilities of Arm, Shoulder and Hand; [3]Mayo Wrist Score
SLA=silicone lunate arthroplasty, RSO=radial shortening osteotomy,TLA= titanium lunate arthroplasty, DRUJ=distal radioulnar joint.

6. DISCUSSION

6.1. THE NATURAL COURSE OF KIENBÖCK'S DISEASE

Kienböck's aetiology is unknown. Disease-related factors, both mechanical, anatomical and systemic, have been reported as causing or exponential factors for osteonecrosis, but no specific cause is known (Beredjiklian 2009, Irisarri 2004, Lluch and Garcia-Elias 2011). There are no prospective therapeutic studies because the rarity of the disease has been a constraint. The spontaneous course of the disease is also not fully known (Beredjiklian 2009, Allan et al 2001, Divelbiss and Baranz 2001, Innes and Strauch 2010, Lutsky and Beredjiklian 2012), although some retrospective follow-up studies have been published (Beckenbaugh et al. 1980, Kristensen et al. 1986, Fujisawa et al. 1996). Defining the spontaneous course of Kienböck's disease would be important because then we would get a better picture of the significance of different therapies for disease pathway and possibly also of the prognosis of disease in individual patients. The organization of research can be difficult because patients are young or middle-aged, for whom the disease poses significant problems, such as work ability. In this case, the long-term outcome is not always crucial for the patient if relief of the symptoms takes a long time. This often turns the treatment line for different operative treatments.

It has been assumed that Kienböck's disease progresses gradually according to the Lichtman and Degnan classification, resulting in worsening symptoms, lunate compression, wrist collapse, and arthrosis. Martini's (1990) study evaluating radiological data on the development of the disease found that variation in progression of the disease was great.

Various information on the results of conservative treatment is available. In the systematic review of Innes and Strauch (2010), the results of early (Lichtman stage I, II, IIIA) and late stage (IIIB, IV) were studied using different treatment methods. The differences were small, minimal, and in discussion, the researchers considered it unclear whether the analyzed interventions differed with placebo or the natural course of the disease.

The results of various and duration varying immobilizations have been published and some retrospective data have compared conservative and operative treatment. However, immobilization can change the natural course of the disease and the mixing factor is also the fluctuating course of the disease. In individual cases, the disease does not always cause symptoms (Golay et al. 2016), when these patients fall from research series.

In an average of 8 years follow-up examination of 33 patients with Keith et al. (2004), the Lichtman stage deteriorated, flexion and the grip strength were reduced, VAS pain did not change, and DASH decreased. Patients were treated with immobilization, a splint, and analgesics.

Ståhl (1947) stated in his dissertation that the result was the best among under 25 years of age and when immobilization took more than two months. The result concerned both ROM, pain, and the grip strength. Lunate's bone structure also improved for the more than two months immobilized patients in about one half and in about 2/3 of those under 25 years old the bone structure looked normal.

Dornan (1949) compared conservatively and with lunate excision-treated patients, most of whom were heavy laborers. Surgery was recommended only if conservative treatment did not work within 3-4 months.

Saffar and Gentaz (1982) published a 120 Kienböck`s patient data, of which 80 were conservatively treated. The stage of the disease gradually worsened, and arthrosis appeared in about 10 years. However, only few had to change their profession due to the disease, while more than half of the patients operated.

Mikkelsen and Gelinek (1987) published 25 plaster-immobilized patient data with a follow-up time of an average of 8 years. Five wrists had an arthrodesis due to pain, and 9 patients had pain with light exertion, five in heavy exertion. Wrist collapse increased, as did arthrosis.

Evans et al. (1986) published data that had conservatively managed 14 patients with an average follow-up of 20 years (Table 2). The result was compared with 21 patients who had been treated with silicone-implant arthroplasty with an average of 5 years of follow-up. The conservative treatment was a leather splint, only three had a plaster of cast, with an average duration of 3.2 years. In Lichtman's classification, the result of conservative treatment was good in 25%, moderate in 37.5%, and poor in 37.5%. Similarly, implant-treated results were 43% good, 37% moderate and 24% very poor due to implant-related problems. In the conservative care group, only one quarter had degenerative changes, and all patients with one exception were able to continue in their job, but in the operative treatment group only 71%.

Salmon et al. (2000) compared conservative treatment with RSO. Conservative treatment was not defined more accurately, and the research was not randomized. Patient groups had been treated in different hospitals and both groups had an average follow-up time of 3.6 years. At follow-up, VAS pain averaged at rest 2.8 in the conservative group and 0.5 in the operative. The Lichtman stage progressed in the conservative group in six patients, with operative progression was slower. The researchers considered that RSO slowed though not inhibiting degenerative changes of the wrist in stage III disease.

Martin and Squire (2013) published a survey that initially consisted of 66 Kienböck patients. Of these, 44 had been treated conservatively with no more

precise definition of treatment, and 18 operatively after conservative treatment resulted to be unsatisfactory, predominantly with partial arthrodesis (11) or total wrist arthrodesis (5). There were no significant differences in DASH scores, in conservative 20 and in operative 23.7. The results may not be comparable because the stage of the disease at baseline was higher in the operative group.

Van den Dungen et al. (2006) compared the result of conservative treatment with the result of STT arthrodesis. Patients were extracted from large material, with conservatively managed 19 and STT-treated 11 (Tables 2 and 5). The demographic data did not differ. In both groups, most of the patients were in Lichtman stage II-III. Conservative treatment comprised night-time splinting and part of the patients had to wear an orthosis also at work. The average monitoring period was 12 years. In the arthrodesis group, barometric pain was significantly higher. There was no difference between DASH scoring, 21 versus 17 in STT arthrodesis. In the conservative treatment group, sick leave was on average 18 days and in the arthrodesis group an average of 120 days. In the conservative treatment group, two and three in the arthrodesis group had changed their profession due to the disease. The disease progressed in both treatment groups. However, STT-arthrodesis did not improve the clinical outcome.

Delaere et al. (1998) published a 42-patient 5-year follow-up in which 22 wrists were conservatively treated with pain-period nighttime splinting and 21 operatetively treated (STT-arthrodesis 11, PRC 6, revascularization 3, RSO 1, ULO 1, denervation 1). There were no significant differences in the results except in extension-flexion, which was 97% of contralateral on conservatively managed and 68% operated. In both groups, two patients were completely painfree and the average grip strength increased slightly. Conservative treatment, which authors assimilate to the natural course of the disease, was satisfactory and operative treatment provided no significant benefits.

Conservative treatment results are varied, but inevitably the clinical outcome is not poor even if the disease radiologically progresses. Most commonly, immobilization is recommended at the early stages of the disease. From the results, with very few studies cannot, however, directly deduce the natural course of the disease. Even after very long follow-up the natural course can be acceptable in a single case (Meek and Lunn 2011).

In the studies on the natural course of Kienböck's disease, the follow-up time varies. In Beckenbaugh et al. (1980) it was an average of 7 years, Fujisawa et al. (1996) 15, Kristensen et al. (1986) 18.2 and in our own research (Study I) 18.1 years.

In Beckenbaugh's study, 10 patients were not operated, because the symptoms were mild or moderate. One had short-term immobilization. Other patients in the study series were operated, 22 had a silicone implant arthroplasty, six arthrodesis,

three lunate excision, one lunate revision and one ulnar lengthening. The result of conservative treatment was compared to the result achieved with these procedures.

Fujisawa et al. (1996) series comprised 17 patients, of whom 12 had been treated with a splint on an average of 5.4 months, of these five 1-2 (mean 1.5) months and five patients only had analgesics. Of these, the last two groups, 10 patients, were included in the material comparison (Table 2).

Kristensen et al. (1986) series consisted of 24 patients (26 wrists) that had been only monitored because the patients did not undertake the planned splint treatment. The result was compared to a group of 22 patients (23 wrists), who were treated with an average of 8 months of plaster immobilization, after which they spent a varying period of time with a splint at their work (Table 2).

In our own series, there were 8 patients (9 wrists), out of which 5 were scheduled only for monitoring, one for a splint treatment, which he did not take, and three for surgery that did not come after the patients (Table 2).

Patients in these studies were therefore in no way randomized to different groups, but the treatment was determined according to symptoms and, on the other hand, to the patients' own decision.

The duration of the pre-diagnosed symptoms was approximately 3 years in Beckenbaugh's entire series, 11 months for Fujisawa et al. (1996), and 9.2 years in our own data. The Lichtman stage was in our own material in seven wrists IIIA and two in IIIB, Fujisawa et al. in two stage II, five stage IIIA and three IV. Other studies did not contain any information on the stage. The average age of the patients ranged from 32 to 43 years.

One patient in Beckenbaugh et al. (1980) series was painfree, the other nine had mild pain. Pain had gradually diminished during the follow-up. All patients were able to continue their work, which was extremely heavy in six situations. From Fujisawa´s et al. (1996) from 10 patients, five were painfree, three had post-stress pain and two intermittent or barometric pain. Of the five patients with no immobilization, three had mild post-stress pain, one barometric, and one intermittent pain. Of 26 wrists of Kristensen et al. (1986), 8 wrists (31%) were painless, 12 wrists (46%) had pain in severe strain and 6 in wrists (23%) under light exertion. After immobilization treatment, pain was similar, 30%, 52%, and 17 %, respectively (Table 2). None of our material was completely painfree. VAS rest pain was 3.1 (0-6.8), pain in mild exercise 3.6 (0.1-8.8) and severe exercise 5.2 (0.5-9.1). All patients continued at work, but at follow-up, only two were in the former job and one advanced supervisor, the others were on retirement due to age.

In our data, DASH was on average 11.3 (0-39.2) and optional, work or leisure DASH 18 (0-56.3). During the first consultation, the DASH assessment was not yet in use. Mayo wrist score averaged 70 (55-85). The result was good (80-90) in two, moderate (65-80) in six and poor (under 65) with one. Other series did not

have a DASH estimate. The symptoms of the wrist were significantly reduced by one patient and by one somewhat, one had no change and in three symptoms had worsened. For two patients, the estimate was missing.

Beckenbaugh did not handle radiological results. In Fujisawa's data, the Lichtman stage was deteriorated in four patients, two from IIIA to IV and two from II to IIIA and IV. Two stage IIIA improved to stage III, one stage IIIA and three stage IV were same as previously. In our own material at first consultation, Lichtman stage IIIA was in seven and IIIB in two wrists and at follow up, two IIIA and two IIIB progressed to Stage IV. In eight wrists there was an average of 5.4 arthrosis index, while in three wrists the change was moderate at index 7-9, but there was no severe arthrosis. Altogether, arthrotic changes were noted in 89% of the wrists. In the study of Kristensen et al (1986), 85% were also found to have arthrosis, all the lunates were deformed and in 33% of the lunates a fracture appeared. The immobilized group did not differ from the mere monitoring group. There was no correction in lunate`s deformation. In our own series, the structure of the lunate improved in three and worsened in three wrists while three remained unchanged. CHR and Ståhl index decreased. In the first consultation, CHR averaged 0.51 and at follow-up 0.48 and Ståhl index 42 and 36, respectively. In Fujisawa et al. (1996), Ståhl index decreased from 34.3 to 30.5. Degenerative changes in our material increased but in five wrists (55%) Lichtman stage remained unchanged at IIIA.

Extension-flexion was on average all the same, Beckenbaugh et al. (1980) 89°, Fujisawa et al. (1996) 96 °, and in our own series 91°. The grip strength was on average 68% of the value of the healthy side (Beckenbaugh 1980), 78% (Fujisawa et al. 1996), and in our series 93%.

Most patients of Van den Dungen et al. (2006), were treated with night splint or splinting during pain periods. At the follow-up, none were completely painfree, which was the result of our own data, too. In Keith et al. (2004) study DASH averaged 30, Van den Dungen's 20.7, and our own on average 11.3, so the functional result is even better.

In Van den Dungen's et al. article, Lichtman stage worsened in 53% and in our own series, in 45%. However, radiological results do not correlate very strongly with clinical findings (Mirabello et al. 1987). Extension-flexion was on average the same; 92 °, and in our own material 91 °. The grip strength was on average 83%, and the present study, 93%. In Keith et al. (2004) series, extension-flexion averaged 98 ° and the grip strength 60% of the healthy side. A few patients had to modify their work, in Van den Dungen's data two (2/19) and two (2/8) in our own data.

The results of our natural data corresponded to the results achieved by splinting or "almost natural course".

Direct comparison with retrospective, surgically treated patients cannot be done, but reflections can be made. In ulna minus variance, Kienböck's disease is commonly treated with RSO. In our RSO data (Study III), follow-up time was longer, averaging 25 years. On the other hand, the symptomatic time in our natural data (Study I) was nearly symmetrical, 27.3 years. RSO patients were younger, the average age was 32.4 years and in the natural data, 43 years.

In Study I, no wrist was completely painless. VAS at rest was 3.1 and under heavy stress 5.2. of the healthy side. In the Study III database, VAS pain at rest was 0.9 and under heavy strain 3.0, with three wrists painless. In other RSO long-term follow-ups, 48-66% of the patients were painfree Koh et al.(2003), Raven et al.(2007), Zenzai et al.(2005), Watanabe et al.(2008), Matsui et al.(2014).

DASH score was in Study I an average 11.3 and in Study III series 6.1. The Mayo wrist score was also better in Study III, on an average of 79, in Study I 70. In Raven`s et al. (2003) RSO data, DASH was 14 and in Watanabe`s et al. (2008), 8. After RSO, 16% (Study III) and 30% (Zenzai et al. 2005) went to lighter work, 12% (one patient) in Study I.

In both series, the wrist became arthrotic, in Study I 89% and in Study III 71%. The index we used in the Study I data was on average 5.4 and in Study III 4.4. Both series had the same amount of arthrosis of radio-ulnar joint. The Ståhl index was also better after RSO, 40 versus 36, and CHR 0.50 versus 0.48.

In Study I and Study III, ROM improved slightly. In Study I extension was 82% and flexion 72% of the healthy side and in Study III 93% and 76%, respectively. The grip strength was in Study I 93% and in Study III 95% of the healthy side. RSO was associated with complications in 37% of the patients and these resulted in revision surgery for 12.5% of the patients, which worsened the treatment outcome.

Long-term monitoring of other procedures saving the lunate has been published for radius and ulna metaphyseal core decompression (Table 5). In Illarramendi`s et al. (2001) 10-year follow-up of 22 patients, 72% of the patients were painfree. Two patients (9%) remained unable to work. Extension-flexion was an average of 77% of the value of the healthy side and the grip strength 75%. Lichtman stage remained unchanged in 17 patients, improved by two and worsened by three. In De Carli`s et al. (2017) mean 13 years follow-up of 15 patients, VAS pain improved from 7 to 1.2 (Table 5). Mayo wrist score improved in all patients, in 8 to good and 6 to excellent. In this study metaphyseal core decompression was done in radius only.The result was similar to RSO result, but follow-up was shorter than that of the RSO reference data. The action mechanism of surgery is not entirely clear, possibly based on the increase in lunate`s increased blood circulation.

The long-term monitoring of our patients in Study I speaks to the fact that Kienböck's disease is progressively advancing but relatively benign in nature. Because of this, even after a very long period of symptoms, at the first consultation

we had no Lichtman stage-IV disease. Collapse of the wrist and of the lunate increased significantly, and 89% of the wrists developed arthrosis, which was mostly mild and did not appear to correlate with clinical outcome. DASH and MWS were somewhat worse than those after RSO, but the ability to work was maintained and the patients had no complications.

Our retrospective, small-scale series does not allow far-reaching conclusions in comparison with other methods of treatment. Our data consisted only of patients at Lichtman stage III, whose treatment for mere monitoring cannot be recommended on the basis of our results, but these results should give rise to further research to determine the natural course of Kienböck's disease.

6.2. SILICONE LUNATE ARTHROPLASTY FOR KIENBÖCK'S DISEASE

Use of the silicone implant in the 1970s became more common in lunate arthroplasty after Swanson introduced his implant (Swanson 1970). In the beginning, treatment appeared to be promising, and in short-term follow-ups (1-3 years) patients had good results 70 to 94% (Roca et al. 1976, Ney 1977, Lichtman et al. 1977, Bertini et al. 1982). The most significant of the initial problems was dislocation or subluxation of the implant, ranging from 9.5% to 30% (Roca et al. 1976, Ney 1977, Lichtman et al. 1977, Bertini et al. 1982, Eiken and Necking 1984, Özsoy et al. 1988), and the same trend emerged in longer follow-up (Ramakrisna et al. 1982, Backaert et al. 1985, Viljakka et al. 1987, Ham et al. 1990). Eiken and Necking (1984) did a comparative study in which a clear distinction appeared between the dorsal and volar approach to dislocations. However, volar implant installation did not become common. The implant was recommended for the disease in its early stages (Lichtman et al. 1977), and in some publications first in stage III (Stark et al. 1981), Ramkrisna et al. (1982), Eiken and Necking (1984).

The appearance of silicone synovitis and cystic changes of the bones was described by Aptekar in 1974 and in the early 1980's; among others, Telaranta et al. (1983) and Ekfors et al. (1984). As implant follow-up times increased, these problems became increasingly apparent. Silicone particles caused wrist synovitis and led to increased cystic changes in the wrists and to wrist degeneration. In mid-follow-up (3 to 7 years), bone changes occurred in 4 of 7 studies (Ramakrishna et al. 1982, Evans et al.1986, Viljakka et al.1987, Alexander et al. 1990). In long-term follow-up, synovitis and cyst formation further increased, and use of silicone implants in conjunction with lunate arthroplasty was no longer suggested (Viljakka et al.1995, Kaarela et al. 1998). In lunate arthroplasties, surgeons began to use interposition of biological material, most commonly a palmaris longus tendon (Kato

et al. 1986, Ueba et al. 1999, Yajima et al. 2004, Matsuhashi et al. 2011, Zeplin and Ziegler 2013, Mariconda et al. 2013), especially in advanced stages of the disease. However, tendon interpositions did not prevent wrist-collapse, and in treatment of Kienböck's disease, other methods have largely replaced the arthroplasties (Allan et al. 2001, Divelbiss and Barantz 2001, Lichtman et al. 2016).

Lunate silicone implant did not result in synovitis for all patients in 20-year follow-up (Viljakka et al. 1995). In order to investigate the results of long-term follow-up, we investigated 54 wrists (53 patients) on average 27.3 (22-36) years after lunate silicone implant arthroplasty.

The clinical and radiological results of the short and medium follow-up of lunate's silicone implant arthroplasty are well documented (Roca et al. 1976, Lichtman et al 1977, Ney 1977, Stark et al 1981, Bertini et al 1982, Ramakrishna et al. 1982, Eiken and Necking 1984, Swanson et al. 1985, Backaert et al. 1985, Evans et al. 1986, Kato et al. 1986, Viljakka et al. 1987, Özsoy et al. 1988, Alexander et al.1990). There exist only a few real long-term follow-ups (Ham et al. 1990, Viljakka et al. 1995, Kaarela et al. 1998).

The primary purpose of this measure is pain relief. However, pain is not evaluated in all publications. In Ney`s series (1977), at 1.5 to 4 years follow-up, 44% of the patients were painfree, and Roca et al. (1976) stated, that at a 2-year follow-up, 60% were painfree. In Stark's et al. (1981) 4-year follow-up study, pain was relieved in 90% of the patients, and Bertini`s et al. study (1982) had a 0.5- to 7-year follow-up in all patients. In Eiken and Necking's (1984) data, pain was relieved in 54% of the patients with a follow-up of 0.5 to 5 years. During the 6-year follow-up of Kato et al. (1986), 39% were painfree; 39% had mild pain. Evans et al. (1986) stated that of his 21 patients, 38 % were painfree, and 38% had slight, and 14% moderate pain after a 5-year follow-up. In Viljakka`s et al.series (1987), the monitoring time of 55 patients was 3 years. At-rest pain had been relieved in 33 (60%), as was pain during exertion in 44 (80%). Those painfree at rest were 36% and during exertion, 11%. Kern and Rodriguez (1988) monitored eight patients after 3 years. Three patients (37%) were painless, others had mild pain. In long-term follow-up, the 18 patients of Ham et al. (1990), were monitored for 12.2 years. Six (30%) were painfree, 10 (55%) had at-exercise pain, and two pain at rest. Viljakka`s et al. (1995) 43 patients were monitored for 11.8 years; 20 patients (46%) had at-rest pain, and 40 patients (93%) had pain during exertion.

In our Study II, at at mean 27 years of follow-up, 52% of the patients were painfree at rest, 21% during mild, and 11% under heavy strain. VAS pain (0-10) was at rest an average of 2.2, and under strain 3.6 and under heavy strain 5.3.

Silicone implant arthroplasty produced pain relief in short follow-up with the proportion of painfree patients being 44% to 60%, 11% to 39% at medium follow-up, 7% to 30% after long follow-up, and 11% in the current study. Depending on

registration method, a large divergence exists in the figures, and the VAS scale was not used previously. In addition, preoperative pain classification is generally lacking, and the same applies to our own research. Long-term follow-up led to an increased proportion of patients with pain.

DASH score in Study II was a 25.4 (0.8-52.7) and optional DASH 27.0. MWS was 64.2 (10-80). In six wrists without cystic changes the respective numbers compared with cystic changes were in DASH score 15.5 versus 27.7, in optional DASH score 6.6 versus 32.3 and in MWS 62.2 versus 55.9.

Flexion of the wrists was, 2 to 11 years after silicone implant arthroplasty, on average 44 ° (34° -75°) (Roca et al. 1976, Lichtman et al. 1977, Stark et al. 1981, Evans et al. 1986, Kato et al. 1986, Viljakka et al. 1987, 1995) and extension in the same studies 51° (38° - 57°). The difference between the operated wrist and the healthy wrist ranged from 58% to 64% in flexion and in extension from 70% to 77% (Backaert et al. 1985, Viljakka et al. 1987, Stark et al. 1981, Viljakka et al., 1995).

In our series, after 27 years, flexion was on average 33° and extension 39°. Flexion was 57% and extension 70% of the contralateral. In only one patient was flexion better than on the healthy side, and in three was equal. Extension remained below the level of the healthy side in all patients, a difference significant in all motions except for flexion. Preoperative flexion was 37.9° and extension 37.3°, so ROM did not change in practice. In three studies, radial deviation averaged 64% (59%-67%) of the healthy side and ulnar deviation 68% (62%-71%) (Viljakka et al. 1987, 1995, Backaert et al. 1985). In Study II, radial deviation was 64% and ulnar deviation 67% of the healthy side. Extension-flexion was smaller than in the shorter follow-up series, with no significant differences in the deviation movement.

Previous releases did not have validated items to estimate function. Grip strength compared to that of the healthy hand was on average 74% (69%-83%) in 9 series (Lichtman et al. 1977, Stark et al. 1981, Bertini et al. 1982, Backaert et al. 1985, Evans et al. 1986, Kato et al. 1986, Viljakka et al. 1987, Ham 1990, Viljakka et al.1995), In the present Study II, grip strength was preoperatively 60.9% and at follow-up 72.2%. The difference from the healthy side was significant ($p< 0.001$).

On an average 3 years of follow-up (Viljakka et al. 1987), 51% of 55 patients were at their former work and 40% doing lighter work. Only 4% had retired due to the wrist disorder. The figures for the follow-up of 11 years (Viljakka et al. 1995) were a respective 56%, 23%, and 7%. At the 27-year follow-up, the figures were 36%, 11%, and 21%. Patient series are not all the same, but the proportion of those able to work is clearly falling. In the series of Kato et al. (1986), 89% did their former work at the 6-year follow-up, but for Evans et al. (1986), only 71% at 5 years.

At our 27-year follow-up, wrist collapse had increased. CHR averaged 0.45 and on the healthy side 0.51, CUDR 0.30 vs. 0.33, RSA 58.6° vs. 50.5°, and lunate covering ratio 42.2 vs. 52.4. All these differences were statistically significant.

Preoperative CHR was 0.49 and CUDR 0.32. CHR remained the same in Kato et al. (1986): 0.52, and in Backaert et al. (1985), 0.51. In Evans et al. (1986), CHR was preoperatively 0.50 and at 5 years 0.48. In Viljakka et al. (1987 and 1995), at 3 years CHR was 0.46 and at 11.8 years 0.45. In the present material, wrist collapse had advanced. In the 3-year and 11-year follow-up groups, the wrists were not exactly same as at 27-year follow-up.

Short follow-ups usually show no indication of arthrosis. Kato et al. (1986) found 44% of patients with arthrosis, and Evans et al. (1986) only one patient (5%). In our data (Viljakka et al. 1987, 1995), mild arthrosis occurred in 76% at their 3-year follow-up and 84% at 11 years, in which cases, preoperative arthrosis was already present in 48% of these patients. At 27 years, arthrosis had occurred in 91%. The arthrosis index (3-15) was on average preoperatively 3.4 and at 27 years 7.7.

Lunate silicone implant arthroplasty is associated with abundant complications, most notably the silicone-related synovitis and the formation of bone cysts in the wrist region. This phenomenon is related to the wear and deformation of the implant, which we monitored in the present study in 11% at one year and at 27 years in 65%. The size of the implant was irrelevant to the presence of cysts, nor was even patient age, duration of symptoms prior to surgery, heaviness of work, nor was the preoperative scaphoradial joint degeneration. In previous publications, the rate of bone cysts was at 3 years 22% (Viljakka et al. 1987) and at 5 years 33% (Swanson et al. 1985). At 8 years, the incidence was 87%, and 41% of the implants had to be removed on average after 5.6 years, all except one for synovitis (Kaarela et al. (1998). At 11 years, the incidence was 81% (Viljakka et al. 1995) and in the present Study II 78%. Cysts were found at one year in 31%, at 5 years in 57%, and at 10 years in 81%. The median time for the emergence of cysts in Study II was 3.7 years. Twelve implants (22%) were removed, nine of which because of silicone synovitis. Six cases were subjected to a wrist arthrodesis. There were no cysts in 12 wrists. Of these, two dislocated implants had been removed and in one wrist, the implant had long been dislocated. One wrist was fused because of pain, and one wrist had spontaneous arthrodesis caused by a deep infection. In one wrist, a finding matched with arthritis and degeneration of many joints. Of the remaining wrists without cysts, in six the result was both clinically and radiologically superior to figures for the entire data. The arthrosis index was 4.5 vs. 10.2 with a significant difference. Thus, only 11% of patients had a good result at 27 years of follow up. Complications associated with silicone implants are thus so common that the method is not recommended, as has been noted (Viljakka et al. 1995, Kaarela et al. 1998).

6.3. RADIAL SHORTENING OSTEOTOMY FOR KIENBÖCK'S DISEASE

The etiology of Kienböck's disease is not uniquely known. Numerous explanatory factors have emerged for this osteonecrosis. Trauma or microfractures have been implicated in many publications (Ståhl 1947, Beckenbaugh et al. 1980), but no evidence is convincing, for example, that lunate dislocations or fractures do not involve osteonecrosis (White and Omer 1984, Teisen and Hjarbaeck 1988). A microtrauma has been considered a potential etiology, but no studies have verified this (Gemne and Saraste 1987, Stahl et al. 2012). Lunate anatomical changes have been assumed to have relevance (Owers et al. 2010, Rhee et al., 2015) as have variations in the lunate circulation (Gelberman et al. 1980, Botte et al. 2004). After Hultén's (1928) study, there appeared e several publications in which the minus variance of the ulna is common in the context of lunatomalacia (Chen and Shih 1990, Bonzar et al. 1998, Afshar et al. 2012). Minus variance as an etiology of Kienböck's disease has not been demonstrated (D'Hoore et al. 1994, Kristensen et al. 1986, Chung et al. 2001, Stahl et al. 2013, Van Leeuwen et al. 2016), however stated that, possibly, ulnar minus variance is a predisposing or aggravating factor for the disease. Racial differences, concerning the occurrence of variance are also possible. The primary etiology of Kienböck`s disease is thus still unknown (Irisarri 2004, Schuind et al. 2008, Lluch and Garcia-Elias 2011).

Various methods have been attempted in treating Kienböck's disease, with attempts made to systematize treatment at the disease's different stages (Allan et al. 2001, Divelbis and Baranz 2001, Luo and Diao 2006, Lichtman et al. 2016). Surgical interventions have concerned observers and led to criticism, because the natural course of the disease has not been revealed, and on the other hand, many complications are associated with surgery (Dias and Lunn 2010). The prevalence of ulna minus variance in lunatomalacia led to procedures in which the load to the lunate was reduced either by shortening the radius or by lengthening the ulna (Hultén 1935, Persson 1945, 1950, Axelsson 1973). In the normal situation, 78% of the load is applied to the radius and from this 46% to the scaphoid fossa and 32% to the lunate fossa of the radius; 22% of the force affects the ulna, with 14% to the ulnolunate and 8% ulnotriquetral joint. The radiolunate load decreased in the normal wrist by 45% as a result of a 4-mm radial shortening (Horii et al. 1990), with 90% of this even achieved by a 2-mm shortening (An1993). The force applied to the distal ulna, causes a 2.5-mm increase by 2.5 mm radial shortening from 20.8% to 44.2% (Werner and Palmer 1993). The force acting on the radiolunar joint reduces RSO and ULO by the same amount (Coe and Trumble 1993). In a CT osteoabsorptiometry study, subchondral bone density decreased at 27 months

after RSO in both the scaphoid and lunate fossa, which was interpreted to mean a significant reduction in the load (Makabe et al. 2011).

6.3.1. Discussion on the results of short-term follow-up after RSO

No prospective studies have been conducted, and all studies, including comparative treatments, are retrospective. This is largely due to the rarity of the disease; published series are, for the same reason, generally small. Radial shortening osteotomy has been used in the early stages of the disease at Lichtman stage (I) II-III. Stage IIIB was not yet that time in use (Goldfarb et al 2003). In 11 studies, the earlier classification of Lichtman et al. (1977) was used instead of Lichtman and Degnan (1993), which has later been the choice, as in our studies. In these studies, with 297 patients the stages and patients were: stage I 1.4%, II 14.5%, IIIA 53.6%, IIIB 28.5%, and IV 0.4%. In stage IIIB, clinical results have been equal to stage II to IIIA results (Weiss et al. 1991, Calfee et al. 2010, Rodriques-Pinto et al. 2012, Matsui et al. 2014), despite the fact, that the radiological result was somewhat worse in stage IIIB. Stage IIIB would thus also be applicable for RSO. In 20 publications, ulnar variance in 385 patients was negative in 74% (mean -1.9 mm), neutral in 15%, and positive in 11%.

Nakamura et al. (1990) emphasized that the primary purpose of osteotomy is lunate decompression, not a leveling of the variance. Nakamura also used RSO in neutral- and in plus variance. However, the shortening should not be excessive, and a shortening of more than 4 mm caused deterioration of the result due to the problems of the radioulnar joint. Shortening of 2 to 3 mm is sufficient (Weiss 1991). Osteotomy has been made even without shortening (Blanco and Blanco 2013) with a 10-year follow-up similar to that of RSO. An explanation would be osteotomy's beneficial effect on lunate blood supply. This is expressed by the study of Nakamura et al. (1993) in which patients were monitored after osteotomy with magnetic resonance imaging for 1 to 3 years, and the control group was conservatively treated. In the operative group, T1 signal intensity was normal or nearly normal in 47% and T2 in the weighted images in 79% of the patients, but those conservatively managed showed no corresponding change.

VAS scales or other pain grading are not generally available when treatment is initiated. Likewise, it is unclear how many of the patients have been unable to work, and what their functional situation has been. The premise is that pain has been the most important factor in the treatment estimate. In the short-term, under a five-year follow-up, 67% (38%-100%) of patients were painfree (Axelsson 1973, Marti et al. 1981, Ovesen 1981, Kinnard et al. 1983, Kuebler and Segmüller 1985, Rajani et al. 1985, Buck-Gramcko and Lankers 1990, Rock et al. 1991, Weiss et al. 1991, Amillo et al. 1993, Quenzer et al. 1997). In some studies, pain is said to

decrease or to be intermittent, but not completely ended (Eiken and Niechajev 1980, Almqvist and Burns 1982, Glas et al. 1988, Messina 1990, Matsushita et al. 1992, DeSmet et al. 1995). At 5 to 10 years of follow-up, 35% were painfree (Nakamura et al. 1990, Altay et al. 2008, Blanco and Blanco 2012, Afshar and Eivaziatashbeik 2013), and at more than 10-year 62% (19%-91%). The number of individuals who are painfree at long-term follow-up seems however to drop. The VAS scale was used only in a few studies. VAS ranged from 0.2 to 3.0 (Salmon et al. 2000, Calfee et al. 2010, Raven et al. 2007, Rodriques-Pinto et. al. 2012, Matsui et al. 2014, Luegmair et al.2017).

Work ability preoperatively is not usually registered in more detail. In seven studies (Axelsson 1973, Almqvist and Burns 1982, Rajani et al. 1985, Kuebler and Segmüller 1985, Condit et al.1993, Blanco and Blanco 2012), 92.5% (83%-100%) of the patients returned to working life and 75% to heavy work (Kinnard et al. 1983).

Grip strength of the hand at least partially demonstrates its ability to function. In less than 5 years of monitoring, grip strength averaged 79% of the contralateral in four publications (Rajani et al. 1985, Matsushita et al. 1992, De Smet et al. 1995, Salmon et al. 2000), 82% in less than 10 years in five (Nakamura et al. 1990, Das Gupta et al. 2003, Altay et al. 2008, Calfee et al. 2010, Afshar and Eivaziatashbeik 2013), and 85 % in more than 10 years in eight publications (Koh et al. 2003, Zenzai et al. 2005, Raven et al. 2007, Blanco and Blanco 2012, Rodriques-Pinto et al. 2012, Matsui et al 2014, Luegmair et al. 2017). Based on these results, the relative grip strength was moderately good.

ROM (extension-flexion) increased to various degrees. In follow-up studies, it was 101° (65° - 132°) in 10 and 82% (73%-91%) of the contralateral in 8. In 18 studies, ROM increased somewhat in all directions. Great variation was evident in recording of these results.

The meta-analysis of Innes and Strauch (2010) showed no significant difference in pain in any treatment group (VBG, metaphyseal core decompression and RSO) at the early stage (Lichtman stage I-IIIA). ROM improved significantly at early stages in the RSO and VBG groups and at late stages in all treatment groups except for the partial arthrodesis- and conservative treatment groups as did grip strength, except for those in conservative treatment. All treatments for the positive effect were characterized by either the breakdown in surgery of the cortex of a carpal bone, the radius, or the ulna.

Lunate radiological structure improved in 20% to 91% of patients (Axelsson 1973, Eiken and Niechajev 1980, Marti et al. 1981, Ovesen 1981, Almqvist and Burns 1982, Kinnard et al. 1983, Glas et al. 1988, Nakamura et al. 1990, Weiss et al. 1991, Quenzer et al. 1997) in 2 to 10 years. During that follow-up period, CHR deteriorated significantly (Weiss et al. 1991, Calfee et al. 2010) or remained unchanged (Blanco and Blanco 2012, Rodrigues-Pinto et al. 2012). Osteoarthritis

was present in 10% (0%-23%) in the same period (Almqvist and Burns 1982, Rajani et al. 1985, Glas et al. 1988, Quenzer et al. 1997, Calfee et al. 2010, Blanco and Blanco 2012). In the meta-analysis (Innes and Strauch 2010), CHR and Ståhl index decreased significantly in the Lichtman stage I-IIIA group only for the RSO.

RSO results were fairly good in short follow-ups and seemed to remain acceptable even after ten years. Radiological changes in some patients were progressing (Van Leeuwen et al. 2016). However, these changes did not necessarily correlate with their clinical outcome (Mirabello et al. 1987). RSO cutoff indications did not coincide in all studies, and the mechanism of action of the surgery itself is still somewhat unclear as the effect of the natural course of the disease is unknown (Dias and Lunn 2010).

6.3.2. Discussion on the results of long-term outcome after RSO

The results of long-term follow-up of the RSO (minimum follow-up ten years) have been presented only four in the literature (Koh et al. 2003, Zenzai et al. 2005, Watanabe et al. 2008, Raven et al. 2009) and after the publication of our article was one (Matsui et al. 2014) (Table 4). The average tracking time ranged from 14.3 (10-21) to 25 (20-33) years, the latter being the follow-up to our own research. One study compared the results of the 14.5-year follow-up to the 5-year follow-up (Koh et al. 2003). Patients ranged from 9 to 25.

In two publications (Koh et al. 2003, Matsui et al. 2014), the youngest patient was 11 years old, in the other 15-23, and the oldest included those 44 to 60 years old. Patients had dropped off 30% (Raven et al. 2009), 60% (Zenzai et al. 2005), and 31% (Watanabe et al. 2008), and our own data came from two of 16 patients (12.5%). One had 2 years after RSO implant arthroplasty and another wrist arthrodesis. They participitated in the study but were excluded from the end results. In two publications (Koh et al. 2003, Matsui et al. 2014,) figures went unmentioned. Average number of males was 73.5%, in our database 79%, and on the dominant side disease was 70.5% on average, but in our own data was that in all patients. The duration of the symptoms was not mentioned in other studies, in our study it was 20 (6-54) months.

The preoperative stage of Lichtman and Degnan (1993) focused on IIIA (46.7%). IIIB was 29.8% and II 23.3%. Stages I and stage IV had just one patient each. Stages IIIB and IV changed from 8.3% to 81.8% in series, with an average score of 30.8%. The lowest was in our own series (8.3%) and the highest in Matsui's (2014) data (81.8%), so the populations were not homogeneous. Ulnar variance varied among groups of patients and within each treatment group was also varied. In Koh's (2003) data, the variance was in all negative, and shortening of the radius was 4 to 6 mm; 10 patients had RSO and 15 patients RCWO. In Zenzai`s (2005)

series of 14 patients, 4 had minus variance, 6 neutral and 4 plus variance; for these last 4, also ulnar shortening osteotomy was performed. The goal was to get a 0- to 2-mm variance. In the Watanabe (2008) data (12 patients), the variance was an average + 1.3 mm. Minus variance occurred in three, neutral variance in four, and plus variance in six patients. The radius was shortened to an average of 3 mm, and the three plus variants had ulnar shortening osteotomy with shortening of 3 to 4 mm. In discussion, the ulnar shortening patients were not analyzed separately in these two studies.

In our data (Study III), ulnar variance was on average -3.0 preoperatively (one patient lacking data) and at follow-up +1.5 (0-5) mm. One of the patients had neutral variance. In Matsui et al. (2014), the variance was negative in nine and neutral in two patients, an average reduction of 2 mm. Usually a compression plate was used for fixing, but three our patients had a spike attachment without problems.

At follow-up, of 14 patients, only 3 (21%) were completely painfree also in exertion. In other publications, pain was absent in 48% (Koh et al. 2003), 66% (Raven et al. 2009), 64% (Zenzai et al. 2005), 50 % (Watanabe et al. 2008) and in 60% (Matsui et al. 2014). Painfree or suffering only slight pain were 92% to 100% of patients (Koh et al. 2003, Zenzai et al. 2005, Matsui et al. 2014). Pain was relieved in 92% (Watanabe et al. 2008). In Study III, patients were asked to evaluate rest pain, motion pain, and pain during mild and severe strain. This question may impact response data, because other studies usually did not ask for pain on exertion. In three studies, VAS pain was 2.4 (Raven et al. 2005), 1.6 (Study III), and 0.8 (Matsui et al. 2014). In the case of pain, a preoperative accurate estimate was generally absent, but the situation in all studies was described better postoperatively than at baseline.

In our own data, six patients (38%) had complications, and four results were estimated to be poor (25%). In two of these, the disease progressed, leading to a new procedure; one received silicone-implant-arthroplasty after 2 years and the other wrist arthrodesis after 16 years. Both came to the final follow-up but were excluded from the results. A third patient was 16 years old with a deformed stage IIIB lunate and a VISI (ventral intercalated segment instability) deformity. The situation of the lunate remained unchanged, and the wrist remained painful. After 25 years, a shortening of the ulna was carried out to remedy an obvious impingement syndrome, but this did not help. The RSO indication might have been questionable, considering the wrist deformity. Of the other two had a radius fracture after a plate removal, and one had ulnar impingement from too-excessive RSO. The fractures were improved by an osteosynthesis, and ulnar impingement was corrected by ulnar shortening osteotomy. The disease of two patients thus progressed and was significantly symptomatic after RSO, and in the third patient, the symptoms did

not ease during long follow-up. For three patients, their complications were mainly related to technical problems.

The four studies included the DASH score in the functional status estimates, and all had the Mayo wrist score. In Raven et al. (2005), DASH-score averaged 14 (0-68), in Watanabe et al. (2008) 8 (0-23), in Matsui et al. (2014) 5 (0-18), and in our own material 6.1(0-23.3). Complications of our data were detrimental to the result, as in the study, the four complicated patients had a DASH score of 11 (0 - 23.3). In a Norwegian population survey, DASH score was 5 among normal healthy women in the age group of 20-29 years and rose to 22 at age 70-79. For men in similar age groups, DASH was 5 and 13 (Aasheim and Finsen 2014).

According to Mayo wrist score, 96% of Koh`s patients (2003) received excellent or good results. Mean MWS was 78 in Zenzai et al. (2005), 83 (63-100) in Watanabe et al. (2008), 92(82-100) in Matsui et al. (2014), and in our own data 79 (60-95). In MWS, 90-100 is excellent, 80-90 good, 65-80 fair, and <65 poor (Cooney et al. 1987).

In the follow-up studies, the radiological situation progressed excluding Matsui's et al.material (2014). In the followings, a change in Lichtman's classification was investigated. In Koh et al. (2003), the stage deteriorated in 9/22 patients (41%) and improved in 2/22 (9%). In Raven et al. (2005), the stage deteriorated in 2/9 patients (22 %), in Zenzai et al. (2005) in 3/14 (21.4%), and in Watanabe et al.(2008) in 6/12 patients (50%). In our Study III, the Lichtman stage worsened in 5/14 patients (35.7%). Koh et al.(2003) had one stage IV patient, as did Zenzai et al.(2005), and Study III had three. CHR did not change in any materials. Preoperative / follow-up ratios were in Koh 0.52 / 0.51 (Koh et al. 2003), in Raven 0.55 / 0.55 (Raven et al. 2005), in Zenzai 0.53 / 0.52 (Zenzai et al. 2005), in Watanabe 0.52 / 0.51 (Watanabe et al. 2008), in our Study III 0.50/0.50, and in Matsui 0.44 / 0.45 (Matsui et al. 2014). The collapse of the wrist did not increase on average. Carpal ulnar distance ratio changed in Koh (2003) from 0.31 to 0.28 and in our Study III from 0.37 to 0.28, which was a significant change, indicating that ulnar translation increased. Ståhl index also changed significantly from 50 to 40 in our own material. The parallel change was in Zenzai et al. (2005) from 34 to 30 and in Watanabe et al. (2008) from 43 to 40. Changes in SRA were small: Zenzai et al. from 62 ° to 68 °, Watanabe et al. 52 ° to 58 °, and in Study III 55 ° to 54 °. Lunate's structure improved in 58% of Koh`s patients. In our own data, the structure of the lunate was improved in all patients. Lunate's shape remained the same or became better 7/14 but deformation also increased in 7/14 patients. In Matsui's data, the signal intensity of the MRI T1 image improved in 6/11 and in T2 in 7/11 patients, with the change being emphasized in young (under 18 years of age) patients. Obviously, the age structure in this material is unusual.

Koh et al. (2003) found radiocarpal arthrosis in 73 % and radioulnar one in 24% of the patients. Zenzai et al. (2005) had arthrosis in 7% and 35.7%, respectively. In our own data, the figures were 71% and 35.7%. Arthrosis was mild, with an average score of 4.4 / 15 (3-8). Arthrosis of the radioulnar joint was mild in 2 patients (index 2/5) and three were moderate to severe (index 4-5 / 5). In these three patients, ulnar variances were on average +3 (1-5) and prosupination movement had a slight limitation, averaging 15 °. In three other publications there was no mention about arthrosis.

Wrist ROM improved in all trials. In the publication of Koh et al. (2003) extension-flexion was significantly improved from preoperative 67% to 82% of the contralateral, In Raven et al. (2005) extension-flexion was 79% to 103%, radial deviation and ulnar deviation 78% to 85% of the contralateral. In Zenzai et al. (2005), ROM also improved considerably with extension 87% and flexion 78%, as did in Watanabe et al. (2008) 82% and 81%. In Matsui et al. (2014), extension improved significantly from 45° to 71° and flexion from 46° to 55°. In our own study, extension improved from 51° to 55°, flexion from 44° to 45°, radial deviation from 19° to 28° and ulnar deviation from 27° to 29°. Extension was 93% and flexion 76% of the contralateral. The change was minor but shows that ROM did not decrease even when the change caused by aging was taken into account. Extension-flexion remained within the acceptable functional limits (DeSmet 2007).

The grip strength improved significantly compared to the preoperative, being 85% of the contralateral (Koh et al. 2003), 90% (Raven et al. 2005), 88% (Watanabe et al. 2008), and 90% (Matsui et al. 2014). In Zenzai et al., 86 % (2005), the change was not significant. In our material, the grip strength was 95% and the key pinch 107% of the contralateral. Koh et al. (2003) also had a five-year follow-up. There was no significant difference between 5-year and 14-year follow-up figures in ROM or the grip strength.

Work ability was not usually preoperatively described. Return to work succeeded in 20/25 of Koh's et al. (2003) patients, of whom 18 were in manual work. Of Raven's et al.(2005) patients, 8/9 returned to their former work and of Watanabe`s et al.(2008) 10/13. In Zenzai`s et al. (2005) material, 10/14 patients were in manual work, of which 6 returned to work, 3 changed their work, and one retired due to wrist disorder. Two patients doing light work had no problems. In our own material 11/16 patients did manual work. Of them 5 continued in the former job, two had moved to a lighter manual job and two were retired due their age. In addition, two were excluded from the final material. One was later subjected to a silicone implant arthroplasty, and he continued in the same work until the retirement age. The other had a wrist arthrodesis, after which he retired. Two of the before-mentioned lightworkers continued in their former job, two were retired due to age and one due to a wrist problem. In the follow-up survey 20 years after RSO,

there were no problems in his wrist. Matsui et al. (2014) did not address working ability. Based on these studies, most patients were able to continue their work requiring the use of a diseased hand.

In Koh's et al.(2003) data, 15/25 of the patients were subjected to radial closing wedge osteotomy. Short follow-up studies have mainly been published in Japan (Nakamura et al. 1991, Miura et al. 1996, Tatebe et al. 2007). Pain, ROM and the grip strength improved. However, the procedure did not prevent the wrist from collapsing.

Wada et al. (2002) published the RCWO-material of 13 patients with an average of 14 years of follow-up (Table 4). Pain decreased for all and 23% of the patients were painfree. Lunate's change progressed in 8/13, CHR deteriorated from 0.51 to 0.48 as well as did Ståhl index from 33 to 27. ROM improved significantly with the preoperative, with extension-flexion at an average of 59°/53°. The grip strength was 98% of the contralateral. Radial closing wedge osteotomy increases the lunate's contact surface with respect to the radius, but the pressure on the lunate does not decrease (Werner and Palmer 1993). Iwasaki et al. (2002) compared RSO and RCWO. Within a short follow-up, both improved pain and function, while the radiological outcome of RCWO was somewhat worse.

Our results on RSO were similar to those of other long-term results. 75% of the patients who went to osteotomy, had a long-lasting improvement the clinical condition and functional capacity. After the operation, the collapse of the wrist blocked or was very limited. The shape of the lunate was maintained in half of the cases. Arthrosis increased but was mostly mild. RSO may then be used in the Kienböck`s disease IIIA stage in patients with negative ulnar variance.

6.4. TITANIUM LUNATE ARTHROPLASTY FOR KIENBÖCK DISEASE

Lunate implant arthroplasty replaces the damaged lunate and at the same time is meant to prevent any collapse or arthrosis that may develop in the wrist. Implants have served as materials, for example vitallium (Lippman and Mc Dermott 1949), acrylic (Agerholm and Goodfellow 1963), and silicone (Swanson 1970). Implant arthroplasty has been associated with material-related problems with silicone (Eiken et al. 1985, Carter et al. 1986), which is why silicone has been abandoned in wrist implants (Alexander et al. 1990, Viljakka et al. 1995, Kaarela et al. 1998). Another major problem is the change in wrist stability as a result of the removal of the lunate and related implant stability disorder and a tendency to dislocate (Evans et al. 1986, Henry 2014). Efforts have been made to improve the stability of the wrist with STT arthrodesis, which, however, also involves problems such as

wrist mobility impairment and radio-scaphoid joint arthrosis (Voche et al. 1992, Minami et al. 1994).

Silicone has been replaced with other more tissue-friendly substances. In 1997, Swanson et al. published their titanium implant data of 21 patients, but no other publications concern the titanium implant. Titanium has been used in many orthopedic implants. Titanium is a biocompatible, lightweight, durable, and chemically inert material with an elastomeric modulus lower than that of steel or cobalt (Davidson and Gergette 1987). Swanson's results were fairly good for 1 to 9 years. The indications for operation were Kienböck's disease stages III-V (roughly corresponding Lichtman and Degnan stages IIIA-IV), including also four revisions of the failed silicone implants.

We decided to use an implant in 11 patients whom we considered appropriate for this method. Among these 11, were 5 ulna-minus variants, all these Lichtman stage IIIB and 6 Lichtman stage IIIA, 3 ulna-plus and 3 neutral variants. In 10 lunates, there was a fracture and fragmentation, and one lunate was badly deformed. Two of them had previously undergone an ossifying procedure unsuccessfully. Thus, RSO was not considered possible or at least its result would have been uncertain. PRC limitation in four patients was young age and workload (Wall et al. 2013) and in four wrists, there was a cartilage injury in the capitate or lunate fossa. It also influenced our past operation culture because we considered the PRC as a late-stage measure, even though there are different perspectives (Bain and Begg 2006). Bain's classification recommended either implant arthroplasty or PRC at frontal fracture of the lunate, grade 2b.

The size of the implant needed was evaluated with experimental specimens so that there was no dislocation tendency, and primary stability was confirmed by the technique described by Swanson et al. (1997) using scaphoid and triquetrum stitches. However, two implants were later dislocated dorsally, and the probable cause was of implant size. In both, Lichtman stage was IIIB. Optimal implant size is not always found in a series of five implants if the wrist is collapsed, and the suture fixation does not necessarily guarantee implant stability. At follow-up, dislocation patients were unwilling to undergo implant removal or other measures and were included in the data. The failure percentage was thus 18 and the result for these two patients was clearly inferior.

The follow-up period of our data was on average 11 years (median 13 years). No preoperative pain grading was available, but all wrists were severely painful, five patients were on sick leave, four had pain at rest, but were at work, and two were retired due to age.

At follow-up, two patients (18%) were painfree, four had pain at rest, three at nighttime, and nine at exertion. VAS pain was at rest on average 0.5 and at exertion 2.7. In Swanson's et al.data, six patients were painfree (28%) and 13 patients had

minimal pain on exertion. In our Study IV DASH score was an average 9.6 (range, 0-25.8) and optional DASH 9.7. DASH scores in two patients with dislocation were 25.8 and 23.3 and in the other nine patients 6.3. Nine patients also had a six-year follow-up when DASH was 9.0. Mayo wrist score was 67.7 (range, 40-80). The result was good in two, moderate in six, and poor in three patients in MWS.

There was no further wrist collapse in the series of Swanson et al., CHR was 0.47, CUDR decresed (0.30 vs .0.27), and RSA was 56°. CHR in the present study was 0.51 and 0.53 on the healthy side. A significant difference was found in the development of arthrosis and in Ståhl index. The average arthrosis score was 4.4 (3-7). In six wrists (55%) there occurred no arthrosis. Ståhl index averaged 66, on the healthy side 49. The difference was significant and suggests that the dimensions of the implant may have differed from those on the healthy side. It is difficult to assess whether this size issue is of practical importance. Carpal ulnar distance ratio slightly increased (CUDR 0.27 vs 0.30), and the lunate- covering ratio decreased (76 vs. 58, p = 0.010), in relation to the slight ulnar displacement of the implant even though the interval between the scaphoid and the implant remained within normal limits (≤ 3 mm).

In our data, ROM improved, an average extension 38°/48°, flexion 32°/44°, ulnar deviation 20°/34°, and radial deviation 17°/21°. The changes were significant compared to healthy side. The respective values in Swanson's et al. data were 38°, 32°, 20°and 17°. Grip strength significantly improved in our material on average from 29.8 kg to 46.3 kg (55%), to 81 % of the value of the healthy side. In Swanson's data, grip strength improved from 19.9 kg to 31.3 kg (57%).

In Swanson's study two patients were unable to return to work (9.5%). One of them had later wrist arthrodesis due to painful arthrosis. In our own study, two patients were on sick leave, one with back problems and one with polymyalgia rheumatica, and all those who did heavy work went on with their former jobs except for the polymyalgia patient. There was one dislocation in Swanson's data that was treated with a new implant. The two dislocations of our own series worsened our results. One patient was able to continue in his former light work and neither wanted new measures undertaken. The second one, who was already retired at the time of surgery, had, one year after the final follow-up, wrist arthrodesis due to pain.

Lunate implants are also made of pyrocarbon with its elasticity being close to the elasticity of the cortical bone. Henry (2014) published results in 13 patients at Lichtman stages III to IV. The average follow-up was 2.5 years. DASH was 7.7 and extension-flexion was 96°, grip strength 31.5 kg (85% of the healthy) ; all were significant changes. Implant fixation was performed by a part of the FCR tendon being pulled through implant channels. The tendon replaced the dorsal scapholunar and lunotriquetrial ligaments. One patient had as a complication osteonecrosis of the proximal part of the scaphoid that that had been treated with PRC. Because

of sagittal instability, one also underwent PRC, so the revision rate was 15%. The author was unsatisfied with the implant, due to the instability problem, despite good results.

Visser et al. (2017) published on a series of 19 patients with Lichtman stage IIIB disease treated by this same technique with a follow-up of 2 years. VAS improved from 5 to 2.6, as did DASH from 31 to 11.Extension-flexion and deviations deteriorated (26° and 14°), the grip strength improved from 22 kg to 29 kg. One patient had PRC due to pain. The measure was considered a good alternative to salvage measures.

If the lunate cannot be saved, PRC has commonly served as a treatment for Lichtman stage IIIB to IV. Publications are mainly mixed series.

Croog and Stern (2008) published on a PRC series with 18 lunatomalacia patients (Table 5). There were 5 at stage IIIA, 12 at stage IIIB, and one at stage IV, followed for 10 (4-17) years. Three stage-IV patients had been removed from the series due to wrist arthrodesis, and in addition, 17 patients had dropped out of the original population. Of the 18 patients, 7 were painfree (39%), DASH score was 12 (0-50). MWS averaged 84(60-100), and 13 patients of 18 achieved a good or excellent result. Extension-flexion was 105° (78%), and grip strength 35 kg (87%). MWS averaged 84(60-100), and 13 patients of 18 achieved a good or excellent result. Arthrosis appeared in 87%. Four of the five heavy-work workers had returned to their former job, all others were in their former light work. Degenerative changes did not correlate with clinical state. In our Study IV, however, the percentage of painfree patients was smaller, but pain was mild. Failure cases were removed from Croog's data, and only half the patients had attended the follow-up. In our data, ROM was worse, DASH better, and arthrosis less.

DeSmet et al. (2005) studied 21 patients, mean age 39 years, with a follow-up of 5 years. Two were at Lichtman stage IIIA, 17 stage IIIB, and two stage IV. Those painfree or mildly in pain numbered 13, with moderate pain for 3, and severe pain for 5 patients. ROM slightly increased, extension-flexion was 72°, ulnar deviation 25°, and radial deviation 16°. Grip strength significantly improved, being 65% (26 kg) of the value of the healthy side. Ten patients returned to their former jobs and five to lighter jobs. Five remained out of work, two of them had CRPS I, and three were already unemployed before surgery. The corresponding readings of our implant data were somewhat better.

Lumsden et al. (2008) had 13 patients with a mean age of 33 (Table 5). All had a stage III disease with an average follow-up of 15 years. Seven were manual laborers. Five were painfree (38%), six had mild and two had more difficult pain. Extension-flexion was of 73% and the grip strength 92% of the healthy side and both improved compared to preoperative. Degenerative changes appeared in 82%,

in 36% moderate or difficult. There were no complications, and everyone returned to work.

It is difficult to compare the result of titanium implant arthroplasty with the results of PRC, as the patients were different from the outset. The PRC problem in long-term monitoring is the development of arthrosis in neo-articulation due to incoherence and cross-sectional load on the joint surfaces (Imbriglia et al.1990).

In the advanced stage of Kienböcks (stages IIIB-IV), a tendon tissue interposition has been used in lunate arthroplasty (Ueba et al. 1999, Mariconda et al. 2013, Zeplin et al. 2013) (Table 3). Ueba et al. had 15 patients with an average of 16 years of follow-up. All patients were painfree and able to work. ROM improved slightly, flexion-extension was 72° preoperatively and at follow-up 85°, and grip strength averaged 90% of that of the healthy side. CHR decreased from 0.53 to 0.49. Arthrosis was not evaluated.

Zeplin`s et al. (2013) series included 10 patients with the disease classified as stages III to IV. The monitoring was 18.5 years. Revision surgery was performed in 20% of the patients. VAS averaged 2.6, DASH averaged 12, and MWS 75. Extension was 65%, flexion 70%, and the grip strength 75% of the value of the healthy side. All had arthrosis in the radiocarpal joint, 70% in the midcarpal joint, and 90% had a carpal collapse. The researchers did not recommend this procedure.

In the 26 patients of Mariconda et al. (2013), the follow-up was 10 years. VAS pain averaged 1 (0-5), DASH was 7.7 (1-26). Extension was 58%, flexion 56%, and grip strength 84% of the value of the healthy side. In MRI, more than half had joint-cartilage lesions, and CHR decreased from 0.49 to 0.45. Despite radiological progress, the clinical outcome was moderately good.

There are variations in the results in different series. Concerning pain, the result was of the same level or better than in our Study IV, as was DASH. Degenerative changes in the joint and collapse of the wrist will degrade the result of the tendon interposition arthroplasty.

There were painfree patients in 10-50% in the natural course series of Kienböck's disease (Beckenbaugh et al. 1980, Kristensen et al. 1986, Fujisawa et al. 1996) and in the conservatively treated series 0 to 24% (Mikkelsen and Gelineck 1987, Dealere et al. 1998, Van den Dungen et al. 2006). Our own, however, comprised not completely painfree patients (Study I); and only 18% of those treated with titanium implants were painfree. VAS pain was in our natural material 3.1 and on exertion 5.2, and in the titanium-implant series, respectively 0.5 and 2.7.

DASH was in our natural data 11.3 and in titanium implant series 9.6 as was well as MWS, respectively 70 and 68. Natural data had arthrosis in 89 % with index 5.4 (3-9) and titanium implant data 45% with index 4.4 (3-7).

Extension-flexion averaged in Study I mean 91°, and the grip strength 93%. In Study IV, the average extension-flexion was 92° (71%) and grip strength 81 %

of the healthy side. In none of Study I and IV, was any patient left unfit for work due to lunatomalacia.

The result of titanium implant arthroplasty was surprisingly good despite of two dislocations of the implant. Comparison of single retrospective results makes it impossible to evaluate the superiority of therapeutic methods, and we cannot safely say whether the long-term result of titanium implant arthroplasty is better than the natural course of the disease. The problem with all implant arthroplasties is in some patients implant instability, which, in particular dislocation, results in a significant deterioration as a result. The preoperative evaluation of patients is important. Possibly, implant design can be further improved and, on the other hand, so can surgical methods to enhance implant stability. Based on our study, titanium does not appear to be associated with similar material-induced complications as silicone.

7. CONCLUSIONS

1. Very little research exists on the natural course of Kienböck's disease. Our patient series was selected because of the mildness of their symptoms. Clinical results (MWS) were good for 22% and satisfactory for 66 % of our patients. Arthrosis was common (89%) but not at any advanced stages, and radiological changes did not correlate with clinical outcome. Due to limitations in the research data, based on this study, watchful waiting as a primary therapy is the method which results we stay waiting for.

2. The result of silicone implant arthroplasty was significantly affected by wear in the implant material and the associated silicone synovitis and bone changes. This complication deteriorated both clinical and radiological results. Silicone-cyst formation increased as a function of time over a period of 10 years, with a median time of onset of about 6 years. Among these patients, 78% showed cystic changes, and only 11% had good clinical, radiological, and functional results. The use of a silicone implant in lunatomalacia is thus not recommended on the basis of this study.

3. Radial shortening osteotomy failed to completely prevent the progression of lunate changes or of wrist degeneration. The failure rate was 25%, and two of these patients were excluded from final screening. Arthrosis changes were mild. The lunate's Lichtman-Degnan stage worsened in 36% of the patients. Mayo wrist scoring was excellent or good in 43 % and satisfactory in 93%, correlating with the long-term results in the literature. RSO can still be used to treat Stage IIIA in patients with ulna minus variance if the clinical situation requires surgical treatment.

4. Titanium has commonly served as an artificial arthroplasty material, but as a replacement material for the lunate bone has been reported on in only one publication. Mayo wrist scoring for our 11-year follow-up was good in 18% and satisfactory in 73 %, with no revision surgery performed during the follow-up period. Arthrosis changes were, in 45% of patients, mostly mild. The problem was instability of the implant, which was not fully achieved by the technique described, and in two patients the implant was dislocated, resulting in a poor outcome. For these reasons, the implant cannot yet be fully recommended for Kienböck's disease.

In all study groups, degenerative changes in the wrist increased. However, arthrosis was mild, except in SLA patients, and severe arthrosis did not generally develop.

In this respect, the course of Kienböck's disease appears to be benign during long-term follow-up. In cases with undergoing surgical treatment, complications had a significant effect on treatment results.

The literature provides data on about 40 different surgical methods for treating Kienböck's disease. Prospective studies based on uniform criteria are essential to determine the natural course of the disease and the effects of these treatment methods.

8. ACKNOWLEDGEMENTS

This study was accomplished at Orton Orthopeadic Hospital and Research Institute Orton in Helsinki, at the University of Helsinki, Finland, and at the Department of Hand and Microsurgery of Tampere University Hospital, Tampere.

I express my most profound and warmest thanks to my supervisor, Professor Martti Vastamäki, whose support and guidance made this work possible. His encouragement and stimulation were essential to ensure that the study succeeded.

I wish to express my deep gratitude to Professor Kaj Tallroth, who also was my supervisor in this study. His great experience in scientific work and radiology provided irreplaceable help and support for me. We also spent a long time together examining and analyzing many hundreds of radiographs.

My sincere thanks to Docent Leena Ristolainen, PT, DSc, for her statistical work and help in the literature search. She always was ready to offer good advice in correcting my writing and in different practical matters during the study.

I wish to extend my warmest thanks to research nurse Ella Haaranen at Orton hospital. She arranged all things: patients, radiographs, and patient documents for us in the best possible way.

Carol Norris, PhD, deserves my special thanks for painstaking linguistic revision of the manuscript.

My sincere thanks to Helena Schmitt, Medical illustrator, for excellent drawings.

I appreciate the constructive and careful review of the manuscript by Docent Olli Leppänen, M.D. and Docent Eero Waris, M.D.to whom go my sincere thanks.

I have good memories of my former chiefs and teachers, Professor Kauko Solonen and Professor Pentti Rokkanen. Both of them made possible for me my specialization in hand and orthopedic surgery in Helsinki and Tampere.

I owe thanks to my colleagues at Tampere University Hospital. Professor Simo Vilkki introduced me to the last study. I had the opportunity to work with hand surgeons Jouni Havulinna, Camilla Hellevuo, Soile Ikola, Nina Tamminen, Tero Kotkansalo, Pasi Paavilainen, and Harry Göransson. They also participated in the treatment of the patients in this study and deserve my true gratitude.

Finally, I am most indebted to my dear wife Liisa for her encouragement and patience during this long project. Without your support I would not declare. I also thank my children Mikko and Jarmo with their families for all the love and devotion you have given me.

This study was financially supported by the Helsinki University Hospital Research Fund (EVO) and The Finnish Society for Surgery of the Hand.

Tampere, January 2020
Timo Viljakka

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